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DRSAR-CPE 76-4

AMMUNITION COST RESEARCH STUDY

JUNE 1976

U.S. ARMY
ARMAMENT COMMAND

TECHNICAL REPORT

Gerald W. Kalal
Patrick J. Gannon

COST ANALYSIS DIVISION (DRSAR-CPE)
HEADQUARTERS, U.S. ARMY ARMAMENT COMMAND
ROCK ISLAND, ILLINOIS 61201

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TECHNICAL REPORT

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13. ABSTRACT

At the complete round level of detail, statistically valid cost estimating tools for independent parametric cost estimates of ammunition investment costs have been difficult to construct. The long life span of ammunition items reduces the number and range of data points available for a given weapon system class (e.g., tank main-armament). To counter this problem, a research project has been undertaken to develop cost estimating tools for ammunition components. This report demonstrates how component-level cost models can be used to independently estimate medium-bore automatic cannon and tank main-armament ammunition investment costs with greater statistical validity than has been obtained with past approaches. The investment cost models cover ammunition initial production facilities (IPF) and procurement.

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14. KEY WORDS	LINK A		LINK B		LINK C	
	ROLE	WT	ROLE	WT	ROLE	WT
Army Cost Analysis Report						
Cost						
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Initial Production Facilities						
Recurring Investment						
Ammunition Procurement						
Learning Curve Analysis						
Cost Estimating Relationships						
Estimating						
Ammunition Cost Estimating						
Transportation of Ammunition						
Medium-Bore Automatic Cannon Ammunition						
Tank Main-Armament Ammunition						
Model						
Cost Model						
Ammunition Components						

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ERRATA SHEET

PAGE 1. Add the following to section I. A. Introduction, Background:

This technical report represents Phase II of the Ammunition Cost Research Project in process at HQ, ARMCOM, Cost Analysis Division. The Phase I report covered medium-bore automatic cannon ammunition, 20mm through 60mm, (see reference 95) and included, under separate cover, ANNEXES A through E (see reference 92). These annexes contain the detailed data used to develop the cost estimating relationships (CER's), cost improvement curves, and analogies related to the recurring investment portion of this project. The Phase II report encompasses Phase I and expands on it to include kinetic energy projectiles, aluminum cartridge cases, and additional data points on several components. Tank main armament ammunition, over 60mm through 152mm, is also covered in the Phase II report.

PAGE 80. Change Table III-9 as follows: at the junction of j=7 and i=3, the value 16.500 should read 10.400, and at the junction of j=13 and i=5, the value 3.00 should read .300.

PAGE 81. Change Table III-10 as follows: at the junction of j=8 and i=26, the value .396 should read .373.

PAGE 105. In the definition for Kinetic Energy: "the mass" should read "the projectile mass".

PAGE 112. Add the following note to the paragraph which follows the CER Data table on page 112:

"The production rates/data base is shown on page 113 under CER Data. The mean which the anticipated production rate is considered to deviate about is identified as the specific mean for the bore size under consideration; i.e., if the LAP cost for a 105mm HE round is being estimated, the mean production rate would be (82K + 102K) ÷ 2 = 92K.

PAGE 118. To the paragraph, "The 20 - 35mm spin-stabilized . . . and profit rate of 12 percent." add, "These CER's estimate the complete projectile (in-flight projectile plus the sabot) cost."

PAGE 121. Change the bottom line, ". . . tungsten alloy as the core material." to read, ". . . tungsten alloy as the core material with tracer capability. If tracer capability is not required, simply subtract $0.73 from the cost estimated."

PAGE 123. Change the paragraph, "The above equation . . . tungsten alloy as the core material." to read, "The above equation . . . tungsten alloy as the core material with tracer capability. If tracer capability is not required, simply subtract $0.73 from the cost estimated."

PAGE 125. Make the following changes:

LnZ = -13.8378 + 3.0885 LnX to read, LnZ = -14.3343 + 3.1763 LnX

$Z = (9.7794 \times 10^{-7})\ X^{3.0885}$ to read, $Z = (5.9523 \times 10^{-7})\ X^{3.1763}$
Coefficient of determination = 0.895 to read, = 0.946
Standard error of estimate in Ln form = 0.588 to read, = 0.399
Mean absolute percent deviation = 36.9 to read, = 33.3

PAGE 125 and 126. The CER Data table should read as follows:

Cartridge Nomenclature	Bore Size(mm)	Actual Unit Cost	Estimated Unit Cost
M56A3 HE	20	$ 0.01	$ 0.01
MK2 HE	40	0.06	0.07
M306A1 HE	57	0.24	0.22
M307A1 HE	57	0.17	0.22
M48 HE	75	0.59	0.54
M42A1 HE	76	0.39	0.56
M352 HE	76	0.63	0.56
M71A1 HE	90	0.92	0.96
M71 HE	90	0.63	0.96
M591 HE	90	0.90	0.96
M323 HE	105	1.88	1.57
M1 HE	105	2.14	1.57
M413 HE	105	0.47	1.57
M548 HE	105	2.24	1.57
M3A1 HE	107	3.08	1.66
M329 HE	107	3.08	1.66
M469 HET	120	1.94	2.39
M356 HET	120	3.41	2.39
M657E2 HET	152	3.76	5.07
M101 HE	155	6.20	5.39
M107 HE	155	5.78	5.39
M549 HE	155	6.88	5.39
M103 HE	203	8.28	12.71
M106 HE	203	14.32	12.71

PAGE 133. Change equation, $C = 122.9027\ R^{0.6590}$ to read $C = 122.9027\ R^{-0.6590}$

PAGE 138. Change equation, $Z = 16.3741\ X^{-2.2678}X^{1.3338}$ to read

$Z = 16.3741\ X^{-2.2678}Y^{1.3338}$

PAGE 157. Change equation (4) to read $V^{-1} - Vo^{-1} = kt$.

PAGE 160. Below equation (6) add the "is greater than" symbol after X^2 and $\frac{v^2}{a^2}$ so that one now reads "where $\coth^{-1} X = \ldots, X^2 > 1$" and, "or $\coth^{-1} \frac{v}{a} = \ldots, \frac{v^2}{a^2} > 1$".

Revised 20 Jan 77

ERRATA SHEET (CONT)

PAGE	
33	1.103 should be 1.155.
41	1.2 should be 1.632 (2 place eqn 28).
41	1,786 should be 2,016 (2 place eqn 29).
65	$Y_{i,k}\ X_{i,j,k}$ should read $Y_{i,k} = N_{i,k}\ X_{i,j,k}$ (eqn 20).
67	the exponent D-25 should be changed to read D-30 for aluminum cases only (eqn 28 only).
91	at i = 17 and j = 5, the value 77 should read .77.
91	at i = 17 and j = 6, insert .77.
95	at i = 5 and j = 1, the value 5.73 should read 573.
95	at i = 5 and j = 3, the value 5.73 should read 4.73.
106	Addressing the value to the right of FY 66 thru FY 57. Change the heading "Under 30mm" to read "Over 30mm". Change the heading "Over 30mm" to read "Under 30mm". Opposite FY 65 is the value 1.62. The value of 1.49 immediately above 1.62 should read 1.58.
136	In the CER Data display, under Cartridge Model, fourth entry from the bottom, M399/M340 should read M339/M340.
---	Throughout this study, the units of mass, momentum, and kinetic energy are:

mass = lbs force per ft per sec^2 = slugs

momentum = lb-sec

kinetic energy = ft-lb

ABSTRACT

At the complete round level of detail, statistically valid cost estimating tools for independent parametric cost estimates of ammunition investment costs have been difficult to construct. The long life span of ammunition items reduces the number and range of data points available for a given weapon system (e.g., tank main-armament). To counter this problem, a research project has been untertaken to develop cost estimating tools for ammunition components. This report demonstrates how component-level cost models can be used to independently estimate medium-bore automatic cannon and tank main-armament ammunition investment costs with greater statistical validity than has been obtained with past approaches. The investment cost models cover ammunition initial production facilities (IPF) and procurement.

AMMUNITION COST RESEARCH STUDY

June 1976

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I. INTRODUCTION

A. BACKGROUND

Preparation of independent parametric cost estimates (IPCE's) for new ammunition proposals has been difficult because of the absence of a comprehensive data base normalized in accordance with consistent and substantiated learning curve assumptions. To compound the difficulty, statistical development of cost estimating relationships (CER's) has traditionally been confined to narrow bands of components or complete rounds. Use of these narrow bands has caused a loss of data points and a reduction in the statistical quality of the results, as well as a limitation of the range of usage. This narrow focus was the natural result of the past emphasis given to estimating costs for specific weapon systems as they reached critical decision milestones rather than planning broad based, long-range studies which addressed multiple systems with many potential ammunition uses.

To correct this problem, the ammunition cost research project was chartered by the Cost Analysis Directorate of the Office of the Comptroller of the Army. The Cost Analysis Directorate charged the Army Materiel Command (AMC) with the responsibility for this study on 20 Mar 75. In turn, AMC assigned the task to the Cost Analysis Division, Headquarters, US Army Armament Command (ARMCOM) on 1 Apr 75.

B. GENERAL APPROACH

The purpose of this study is to develop investment cost-estimating tools for medium-bore automatic cannon and tank main-armament ammunition which will facilitate independent cost estimates. These tools must be applicable to prevalent types and calibers of ammunition produced at various production rates and program quantities so that wide ranges of ammunition proposals can be estimated easily and independently. The results of this study are intended to support the decision making process early in the acquisition phase. They are not intended to be used for current procurement actions.

The developed tools feature the following:

1. For nonrecurring investment; matrices, which are listings of capital equipment and associated tooling, to be manipulated by a computerized cost model to generate lines-of-balance for each ammunition component and their resultant costs.

2. For recurring investment; cost predictors at the component level of detail which can statistically predict costs based upon physical and performance characteristics.

Data acquisition was as follows:

1. For investment nonrecurring, emphasis was placed on establishing a data base founded on hard data such as descriptions of manafacture (ref 1 is typical). Equipment lists, which became the data base, were synthesized by analyzing the manufacturing processes necessary to produce each of the associated ammunition components. Where hard data was unavailable, equipment lists were provided by the responsible engineering agency.

2. For investment recurring, priority was given to the use of hard procurement data. These data were selected because they represent actual procurement practices. Data adjudged by price analysts as being unsuitable for procurement uses were excluded. The exclusions were made prior to the beginning of the cost-research project in a completely independent action. When hard procurement data were not available because of the obsolescence of an ammunition item, a cost estimate was obtained from the responsible engineering agency to fill out the independent variable continuum.

C. ACKNOWLEDGEMENTS

While the Cost Analysis Division, HQ, ARMCOM performed a central role in data collection and study coordination, completion of the project would not have been possible without the suggestions and assistance provided by HQ, ARMCOM Directorates of Research, Development, and Engineering; Procurement and Production; Quality Assurance; Materiel Management; Maintenance; and Transportation and Traffic Management, in addition to the Systems Analysis Office. Special estimating and data collection efforts were provided by the employees of Frankford and Picatinny Arsenals to satisfy the broad scope of the study. Valuable data and advice were received from both the Department of the Air Force and Department of the Navy.

II. STUDY RESULTS

A. GENERAL ESTIMATING METHODOLOGIES

The primary approach proposed by this study for developing investment cost IPCE's is mathematical modeling and CER's. The study results successfully demonstrate that component level development of cost models and CER's should be used rather than attempting to prepare such models and relationships at the total round level.

While the component approach does not eliminate difficulties when advances in ammunition technology are incorporated into a new ammunition proposal, structuring the estimate at the component level limits these problems to the components involved in the change. When using total round level CER's and when faced with a new kind of component, such as a telescoped cartridge case, the estimator must reduce the reliability of the total estimate with a complexity factor or abandon use of the CER entirely. With component CER's the estimator need only adopt alternate estimating techniques for the components that are unique.

This study does not attempt to give specific guidance for handling new and unused technologies. It is not possible to foresee all problems, or to predict their solutions. However, on the basis of shortages in the data base and from the experiences gained in developing the models and CER's, certain problems can be foreseen. They are:

1. The lack of Army experience with dual-purpose high explosive and discarding sabot projectiles, as well as aluminum, telescoped, and combustible cartridge cases.

2. The general difficulty of fuze estimating, which not only includes technological changes with the introduction of electronic componentry, but also lacks strong cost drivers for initial parametric estimating.

The remainder of section II is split between reporting the results for initial production facilities and presentation of the cost estimating parameters prepared for ammunition component production costs. The use of the IPF model is illustrated by a simplified example along with a narrative "walk-through". The use of the recurring cost estimating parameters is illustrated with an example estimate.

B. NONRECURRING INVESTMENT

1. Estimating Model

Prior to preparation of an independent parametric cost estimate (IPCE) of initial production facilities (IPF), it is essential to obtain a clear statement of machinery requirements for the family of ammunition to be produced. To obtain this requirements statement, it is first necessary to determine the mobilization plan for the ammunition being introduced to the Army. Then it is necessary to determine whether the existing base of machinery is sufficient to meet the mobilization plan. If this base is not sufficient, then the short fall must be specified at the component level of detail. Only then can a realistic IPCE be prepared.

The resulting mobilization output rate for each component and the corresponding short fall from the desired output rate must be the agreed upon basis for both the IPCE and the Baseline Cost Estimate (BCE) being compared. Given that the outputs are properly defined, it was determined that cost modeling is the best way to independently estimate the machinery required to support a new ammunition family.

The proposed cost estimating model, definitions of the mathematical notation used, and accompanying rationale and procedural explanations are included in section IIIB. Due to the level of detail at which cost estimates are generated, it is intended that the model be exercised by computer. Therefore, this section is confined to a general description of the coverage provided by the model and the estimating algorithm.

The estimating model covers the cost elements of industrial production equipment (IPE), special initial tooling, and test and measuring equipment for ammunition at the component and load, assemble, and pack (LAP) levels over the 20mm - 60mm medium-bore and the over 60mm - 152mm tank main armament size ranges. Separate estimates can be obtained for the last two cost elements if the estimate guidance precludes the inclusion of IPE. The components and size ranges covered are shown in the following table.

TABLE II-I NONRECURRING INVESTMENT COST MODEL COVERAGE

	20-30mm	Over 30mm - 60mm	Over 60mm - 152mm
IPE			
Projectile (HE, AP, and TP)	X	X	X 1/
Link	X		
Box	X		
LAP	X	X	X
Cartridge Case	X	X	X
Fuze	X	X	X
INITIAL TOOLING			
Projectile (HE, AP, and TP)	X	X	X 1/
Link	X		
Box	X		
LAP	X	X	X
Cartridge Case	X	X	X
Fuze			X

	20-30mm	Over 30mm - 60mm	Over 60mm - 152mm
TEST AND MEASURING EQUIPMENT			
Projectile (HE, AP, and TP)	X	X	X 1/
Link	X		
Box	X		
LAP	X	X	X
Cartridge Case	X	X	X
Fuze	X	X	X

1/ There is no AP projectile in the 152mm family of ammunition.

Once the mobilization plan has been determined, and the IPE shortfall in terms of scheduled numbers of rounds has been specified at the component level, the annual production quantity of each component requiring IPE or initial tooling and test and measuring equipment is used as input to the estimating model. The required additional inputs are the assumed number of production shifts per day, projectile length and diameter, cartridge case length, and number of rounds per box.

An estimating data base is included in the model as matrices which provide listings of IPE, equipment-unit costs, equipment-production capacities per shift, and average unit-tooling costs per equipment item. The matrices are shown in section IIIB as Tables III-2 through III-33. Estimates of test and measuring equipment are included in the model also.

The capital equipment and tooling portrayed in each of the matrices represents a way of producing a given ammunition component, based on available descriptions of manufacture (ref 1 is typical) or as provided by the responsible engineering agency. The processes reflect the degree of sophistication required, dictated to a large extent by the annual production requirements (visualize the requirements for small arm ammunition versus tank main armament ammunition). Though this study is based on established processes and equipment which, for all practical purposes, is currently available on the market, it is not fully representative of any facility presently in operation.

Cost estimates are obtained through the solution of a series of cost equations for each component and LAP. By means of the equations, the estimating model performs the following:

a. The number of machines required is estimated based upon:

(1) annual production requirements (inputs to the model).
(2) the assumed number of shifts (inputs to the model).
(3) equipment item capacity per shift (included in the data base).
(4) the number of rounds per box when boxes are necessary (input to the model).

(5) for ammunition over 30mm to 60mm, the model selectively applies dimensional adjustments, employing cartridge-case and/or projectile dimensions (inputs) for size variations which affect equipment-production capacities. This also applies to the alternative B, 20 - 40mm model.

b. The total cost of individual equipment items is estimated based on the number of machines required and the equipment item unit cost (data base).

c. The estimated cost of all equipment required for each component and LAP is summarized. The estimated cost of test and measuring equipment (data base) is added, and allowances are applied as applicable for transportation, installation, layaway, and miscellaneous material handling equipment included in the cost equations.

d. The cost of the initial tooling for each equipment item is estimated based on the number of machines required and the average unit-tooling cost per equipment item (data base).

e. The estimated cost of initial tooling for all equipment required for each component and LAP is summarized.

The basic model intrinsicly identifies requirements for high, medium, and low production rate capabilities to the 20 - 30mm, over 30 - 60mm, and over 60 - 152mm ranges, respectively. This identification is made to explain why there also is presented a 20 - 40mm IPF matrix range.

The 20 - 30mm model is based on a 25mm ammunition configuration. A plus or minus 5mm's about the 25mm base would not affect the equipment capacity, and thereby equipment quantities, enough to cause a significant change in the single estimated total cost through this narrow range of application; that is, the resulting estimate would be within acceptable estimating tolerances.

A recent requirement for IPF estimates covering a 20 - 40mm range and high production rate capabilities generated a separate study, the HQ, ARMCOM, Cost Analysis Division, Technical Report CPE 76-3. entitled: Modified Cost Estimating Model for 20 - 40mm Automatic Cannon Ammunition Initial Production Facilities, Apr 76. Simply stated, this effort primarily consisted of applying dimensional adjustments to the basic 20 - 30mm model to account for size effect on equipment capacity and extending the model to include 40mm ammunition. This means of adjustment is similar to that applied to the basic over 30 - 60mm model.

The results of the above are presented in section III as alternative A, covering the 20 - 60mm range; and alternative B, covering the 20 - 40mm model. The latter are extracted directly from Technical Report CPE 76-3.

2. Use of the IPF Model to Estimate Cost

Due to the level of detail at which cost estimates are generated, it is intended that the IPF model be exercised by computer. However, to illustrate its use, a simplified example is presented below.

To manufacture an ammunition component, a production line is required, comprised of an assortment of capital equipment items (line-of-balance) and associated special tooling. From the aggregate of equipment displayed in the simplified table below, it will be demonstrated how a line-of-balance is developed for a given production requirement. The table identifies each item of capital equipment required, its unit cost in thousands of dollars, its annual capacity/shift in millions of units, and the associated unit cost of tooling in thousands of dollars. It is noted that the average cost per set of tooling decreases as the quantity of tool sets required increases.

No.	Equipment Item	Equipment Unit Cost	Equipment Capacity/Shift	Avg Tooling Cost/Set 1	2	3	4
1	Auto Screw Mach	$78	0.4	7.7	5.6	4.0	4.0
2	Centerless Grinder	36	2.5	4.4	3.3	2.9	2.9
3	35 Ton Press	15	1.7	2.2	1.7	1.5	1.5
4	Rotary Trimmer	21	1.9	0.8	0.7	0.6	0.6
5	Paint Mach	44	2.3	0	0	0	0

Given an annual production requirement, the quantity of each item of equipment needed to meet this demand is determined by dividing each equipment item's capacity into this requirement. If this quotient contains a fraction, it is rounded to the next larger integer.

Multiply the quantity of each item of equipment determined above by its unit cost. The sum of these products is the total estimated cost for the capital equipment items required to meet the stated demand.

This summation is now multiplied by a factor to account for layaway costs, installation and transportation costs, and miscellaneous material handling equipment costs as appropriate. To this adjusted summation is added the cost for test and measuring equipment (TME).

The estimated cost for tooling is determined in the same fashion, using the quantity of equipment items previously determined and the average unit tooling costs shown for the varying quantity of equipment items. The factors for layaway, installation and transportation, miscellaneous material handling equipment, and TME are not applicable to the tooling cost estimate.

Applying the above methodology to a requirement of five million units a year and a one-shift operation, the following results:

Item No.	Equipment Qty Calculated	Equipment Qty Rounded	Total Equip Cost In Thousands	Total Tooling Cost In Thousands
1	12.5	13	$1,014	$52.0
2	2.0	2	72	6.6
3	2.9	3	45	4.5
4	2.6	3	63	1.8
5	2.2	3	132	0
			$1,326	$64.9

The total cost of the equipment required is $1,326K. This is now multiplied by 1.155, to account for transportation and installation at five percent and layaway at ten percent, resulting in an estimated cost of $1,532K. The total estimated cost equates to $1,649K (consisting of the $1,532K plus $52K for TME plus $65K for tooling).

The foregoing example represented a one-shift operation. If a two- or three-shift operation is to be considered, simply divide the quotient previously determined by the number of shifts being considered. This new quotient is rounded up as previously discussed, resulting in the new quantity of each item of capital equipment required.

C. RECURRING INVESTMENT

1. Estimating Parameters

The recurring investment portion of the study is confined to the contractor costs and excludes costs for in-house engineering and quality assurance support. A deterent to preparing estimating statistics covering support costs is the absence of an accounting system which collects support costs allocated to the procurement of complete rounds and components. The support costs are a minor factor of total life cycle costs and are, therefore, not a particular problem for the estimator when preparing an IPCE.

The cost estimating parameters that result from this study are primarily supported by hard procurement data and engineering estimates. The hard data cover procurements from 1957 through 1975. The collection of data was conducted in accordance with the procedures outlined in section IIIC1. Composite learning rates were developed by component and are presented in detail in section IIIC2. Component production cost predictor's are recommended in accordance with the findings of section IIIC3. Finally, a transportation CER is suggested in accordance with section IIIC4.

The recommended composite learning rates and cost predictors for ammunition recurring costs are:

LAP Composite learning rate is 100 percent.

HE and HEAT

$$\mathrm{Ln}Z = -6.8639 + 2.1143\ \mathrm{Ln}X$$

where: Z = Estimated unit cost in FY 74 dollars
X = Bore size in millimeters

AP

$$\mathrm{Ln}Z = 2.9272 - 0.000002941\ X + 0.9583\ \mathrm{Ln}Y$$

where: Z = Estimated unit cost in FY 74 dollars
X = Average annual production rate in thousands
Y = Projectile mass

TP

$$\mathrm{Ln}Z = 4.1000 - 0.3247\ \mathrm{Ln}X + 0.6453\ \mathrm{Ln}Y$$

where: Z = Estimated unit cost in FY 74 dollars
X = Average annual production rate in thousands
Y = Projectile mass

PROJECTILE Composite learning rate is 92.6 percent for HE, HEAT, full-bore AP and TP.

HE

$$\mathrm{Ln}Z = -1.6983 + 1.3739\ \mathrm{Ln}X$$

where: Z = Estimated theoretical first-unit cost in FY 74 dollars
X = Bore size in millimeters

FULL-BORE AP

$$\mathrm{Ln}Z = -3.9018 + 1.7971\ \mathrm{Ln}X$$

where: Z = Estimated theoretical first-unit cost in FY 74 dollars
X = Bore size in millimeters

20-35MM SPIN-STABILIZED APDS

Depleted Uranium

$$Z = (7.8372 + 2.2988T) - (0.6730 + 0.1897T)\ \mathrm{Ln}X + (223.7385 + 72.9148T)\ Y$$

Tungsten Alloy

$$Z = (8.6845 + 1.6398T) - (0.9030 + 0.1620T)\ \mathrm{Ln}X + (728.3217 + 111.8573T)\ Y$$

where: Z = Estimated unit cost in FY 75 dollars
X = Average annual production rate in thousands
Y = In-flight projectile mass
T = Tracer cavity conditional code

75-152MM SPIN-STABILIZED APDS

$$Z = \mathrm{Antiln}(2.9061 + 0.009663X) + (85.67 + 90.66T)\left(\frac{Y}{0.2640}\right) + 20.68\left(\frac{Y}{0.2640}\right)^{0.6667}$$

where: Z = Estimated unit cost in FY 76 dollars
X = Full-bore size in millimeters
Y = In-flight projectile mass
T = Material type conditional code

FIN-STABILIZED APDS

$$Z = \mathrm{Antiln}(3.1417 + 0.009529X) + (116.91 + 52.80T)\left(\frac{Y}{0.2640}\right) + 16.73\left(\frac{Y}{0.2640}\right)^{0.6667}$$

where: Z = Estimated unit cost in FY 76 dollars
X = Full-bore size in millimeters
Y = In-flight projectile mass
T = Material type conditional code

TP

$$\mathrm{Ln}Z = -5.5868 + 2.1305\ \mathrm{Ln}X$$

where: Z = Estimated theoretical first-unit cost in FY 74 dollars
X = Bore size in millimeters

EXPLOSIVE FILL Composite learning rate is 100 percent.

HE

$$\mathrm{Ln}Z = -13.8378 + 3.0885\ \mathrm{Ln}X$$

where: Z = Estimated unit cost in FY 74 dollars
X = Bore size in millimeters

HEAT

$\ln Z = -12.3829 + 2.6706 \ln X$

where: Z = Estimated unit cost in FY 74 dollars
X = Bore size in millimeters

HEP

$\ln Z = -3.7946 + 0.05190\ X$

where: Z = Estimated unit cost in FY 74 dollars
X = Bore size in millimeters

CASE Composite learning rate is 94.3 percent for brass and steel.

BRASS

$\ln Z = 0.6833 + 0.02674\ X + 0.5731\ Y$

where: Z = Estimated theoretical first-unit cost in FY 74 dollars
X = Bore size in millimeters
Z = Projectile mass

STEEL

$\ln Z = 1.0625 + 0.02063\ X + 0.2022\ Y$

where: Z = Estimated theoretical first-unit cost in FY 74 dollars
X = Bore size in millimeters
Y = Projectile mass

ALUMINUM

$Z = 0.001188\ X + 0.00002852\ X^3 + 122.9027\ Y^{-0.6590}$

where: Z = Estimated unit cost in FY 75 dollars
X = Bore size in millimeters
Y = Average annual production rate in thousands

COMBUSTIBLE

$\ln Z = 1.2865 + 0.01015\ X$

where: Z = Estimated unit cost in FY 74 dollars
X = Bore size in millimeters

PROPELLANT Composite learning rate is 100 percent.

$\ln Z = -10.5840 + 0.01571\ X + 0.7416 \ln Y$

where: Z = Estimated unit cost in FY 74 dollars
X = Bore size in millimeters
Y = Kinetic energy

PRIMER

PERCUSSION Composite learning rate is 89.7 percent.

$\ln Z = 2.7957 - 2.2678 \ln X + 1.3338 \ln Y$

where: Z = Estimated theoretical first-unit cost in FY 74 dollars
X = Round application bore size in millimeters
Y = Round application momentum

ELECTRIC Composite learning rate is 80.3 percent.

$$\text{Ln}Z = -14.1220 + 4.0538\ \text{Ln}X - 0.9031\ \text{Ln}Y$$

where: Z = Estimated theoretical first-unit cost in FY 74 dollars
X = Round application bore size in millimeters
Y = Round application projectile mass

LINK Composite learning rate is 100 percent.

Bore Size	Unit Cost in FY 74 dollars
7.62mm	$0.0127
12.7mm	0.0467
20mm	0.2413
40mm	0.2645

FUZE Composite learning rate is 91.1 percent.

PD

$$\text{Ln}Z = 14.0768 - 2.2258\ \text{Ln}X + 1.0590\ \text{Ln}Y$$

where: Z = Estimated theoretical first-unit cost in FY 74 dollars
X = Round application bore size in millimeters
Y = Round application projectile mass

BD

$$\text{Ln}Z = 0.6493 + 0.5905\ \text{Ln}X + (2.0698 \times 10^{-7})\ Y$$

where: Z = Estimated theoretical first-unit cost in FY 74 dollars
X = Round application bore size in millimeters
Y = Round application kinetic energy

PIBD

$$\text{Ln}Z = -52.3486 + 11.5814\ \text{Ln}X - 4.0205\ \text{Ln}Y$$

where: Z = Estimated theoretical first-unit cost in FY 74 dollars
X = Round application bore size in millimeters
Y = Round application projectile mass

TRANSPORTATION

$$\text{Ln}Z = 1.5214 + 1.0029\ \text{Ln}X$$

where: Z = Estimated unit cost in FY 75 dollars
X = Projectile mass

2. Development of a Procurement Plan for the Family of Ammunition

Independent parametric cost estimates (IPCE's) are based upon historical cost data and those factors that accomplish the mission of the system. One of these factors that must be considered during the IPCE is the procurement plan for the family of ammunition being studied.

The plan must be for the complete life cycle of the system using the ammunition. In developing the plan, higher headquarters should provide guidance to ascertain levels of procurements. Before preparing the IPCE, it is necessary to answer the following questions:

a. What will the authorized acquisition objectives (AAO's) be for each round used by the system?

b. How many years of procurement will be required to fill the AAO?

c. What will the annual rate of consumption be for each round used?

d. What will the annual procurement rates be to maintain existing AAO levels?

Special emphasis for procurement planning is addressed in section IVB.

3. Use of Estimating Parameters to Estimate Total Cost

Use of the estimating parameters is illustrated with this detailed example of estimating the total ammunition recurring cost utilizing the cost predictors and composite learning rates presented in section IIC1. Since the recurring cost estimating parameters are presented at the ammunition component level, the first step in the procedure is to estimate the total cost of each component. The total ammunition recurring cost is the sum of the total component costs.

Suppose a cost estimate is required for two 30mm rounds of ammunition including a quantity of 10 million HE rounds, designated by M100, and 20 million TP rounds, designated by M200. The annual production rates are 4 million and 8 million for the M100 and M200, respectively. The M100 incorporates a point-detonating fuze. Both rounds incorporate the same cartridge case. The physical and performance characteristics of the two rounds are as follows:

	M100 HE	M200 TP
Bore size	30mm	30mm
Projectile mass (M)	0.030	0.020
Muzzle velocity (V)	3,000 fps	3,000 fps
Momentum (MV)	90	60
Kinetic energy ($0.5MV^2$)	135,000	90,000
Case	Brass	Brass

The component total costs are estimated as follows:

LAP

HE

$$\begin{aligned} \text{LnZ} &= -6.8639 + 2.1143 \text{ LnX}; \; X = \text{Bore size (mm)} \\ &= -6.8639 + 2.1143 \text{ Ln30} \\ &= 0.3273 \\ Z &= \$1.387 \text{ per round} \end{aligned}$$

The total LAP cost for the M100 is $1.387(10,000,000) = $13,870,000.

TP

$$\begin{aligned} \text{LnZ} &= 4.1000 - 0.3247 \text{ LnX} + 0.6453 \text{ LnY}; \; X = \text{Annual production rate (K)}, \\ &\quad Y = \text{Projectile mass} \\ &= 4.1000 - 0.3247 \text{ Ln8,000} + 0.6453 \text{ Ln0.020} \\ &= -1.3426 \\ Z &= \$0.261 \text{ per round} \end{aligned}$$

The total LAP cost for the M200 is $0.261(20,000,000) = $5,220,000.

PROJECTILE

HE

$$\begin{aligned} \text{LnZ} &= -1.6983 + 1.3739 \text{ LnX}; \; X = \text{Bore size (mm)} \\ &= -1.6983 + 1.3739 \text{ Ln30} \\ &= 2.9746 \\ Z &= \$19.582 \text{ for the first unit} \end{aligned}$$

Using a 92.6 percent learning rate, the total projectile cost for the M100 is $36,855,500.

TP

$$\begin{aligned} \text{LnZ} &= -5.5868 + 2.1305 \text{ LnX}; \; X = \text{Bore size (mm)} \\ &= -5.5868 + 2.1305 \text{ Ln30} \\ &= 1.6595 \\ Z &= \$5.257 \text{ for the first unit} \end{aligned}$$

Using a 92.6 percent learning rate, the total projectile cost for the M200 is $18,324,200.

EXPLOSIVE FILL

HE

$$\begin{aligned} \text{LnZ} &= -13.8378 + 3.0885 \text{ LnX}; \; X = \text{Bore size (mm)} \\ &= -13.8378 + 3.0885 \text{ Ln30} \\ &= -3.3332 \\ Z &= \$0.036 \text{ per round} \end{aligned}$$

The total fill cost for the M100 is $0.036(10,000,000) = $360,000.

CASE

HE and TP-Brass

$LnZ = 0.6833 + 0.02674\ X + 0.5731\ Y$; X = Bore size(mm), Y = Projectile mass

$= 0.6833 + 0.02674(30) + 0.5731(0.030)$

$= 1.5027$

$Z = \$4.494$ for the first unit

Using a 94.3 percent learning rate, the total cost for the M100 and M200 is $34,283,600.

PROPELLANT

HE

$LnZ = -10.5840 + 0.01571\ X + 0.7416\ LnY$; X = Bore size(mm), Y = Kinetic energy

$= -10.5840 + 0.01571(30) + 0.7416\ Ln135{,}000$

$= -1.3522$

$Z = \$0.259$ per round

The total propellant cost for the M100 is $0.259(10,000,000) = $2,590,000.

TP

$LnZ = -10.5840 + 0.01571(30) + 0.7416\ Ln90{,}000$

$= -1.6528$

$Z = \$0.192$ per round

The total propellant cost for the M200 is $0.192(20,000,000) = $3,840,000.

PRIMER

HE and TP-Percussion

$LnZ = 2.7957 - 2.2678\ LnX + 1.3338\ LnY$; X = Bore size(mm), Y = Momentum

$= 2.7957 - 2.2678\ Ln30 + 1.3338\ Ln90$

$= 1.0843$

$Z = \$2.957$ for the first unit

Using an 89.7 percent learning rate, the total primer cost for the M100 and M200 is $7,071,100.

LINK

Based upon historical unit costs of $0.2413 for 20mm links and $0.2645 for 40mm links, a 30mm link is estimated to cost $0.253. The total link cost for the M100 and M200 assuming 30 million links is $0.253(30,000,000) = $7,590,000.

FUZE

HE-PD

$LnZ = 14.0768 - 2.2258\ LnX + 1.0590\ LnY$; X = Bore size(mm), Y = Projectile mass

$= 14.0768 - 2.2258\ Ln30 + 1.0590\ Ln0.030$

$= 2.7930$

$Z = \$16.330$ for the first unit

Using a 91.1 percent learning rate, the total fuze cost for the M100 is $21,595,700.

TRANSPORTATION

HE

$$\ln Z = 1.5214 + 1.0029 \ln X; \quad X = \text{Projectile mass}$$
$$= 1.5214 + 1.0029 \ln 0.030$$
$$= -1.9953$$
$$Z = \$0.136 \text{ per round}$$

The total transportation cost in FY 75 dollars for the M100 is $0.136(10,000,000) = $1,360,000. The M100 transportation cost in FY 74 dollars is 0.83($1,360,000) = $1,128,800.

TP

$$\ln Z = 1.5214 + 1.0029 \ln 0.020$$
$$= -2.4020$$
$$Z = \$0.091 \text{ per round}$$

The total transportation cost in FY 75 dollars for the M200 is $0.091(20,000,000) = $1,820,000. The M200 transportation cost in FY 74 dollars is 0.83($1,820,000) = $1,510,600.

The total ammunition recurring cost in FY 74 dollars by round is summarized below. The case, primer, and link total costs are apportioned to the M100 and M200 rounds based upon the quantity of each round.

	(Costs in millions) M100 HE	M200 TP
LAP	$13.870	$ 5.220
Projectile	36.856	18.324
Explosive Fill	0.360	NA
Case	11.428	22.856
Propellant	2.590	3.840
Primer	2.357	4.714
Link	2.530	5.060
Fuze	21.596	NA
Transportation	1.129	1.511
TOTAL	$92.716	$61.525

The total ammunition recurring cost is estimated at $154.241 million in FY 74 dollars.

III. STUDY METHODOLOGY

A. SPECIAL AMMUNITION PROCUREMENT CONSIDERATIONS

The uniqueness of ammunition procurement practices is attributed to the number of manufacturers involved. It is not uncommon to find a mixture of contractor owned contractor operated (COCO) plants, Government owned contractor operated (GOCO) plants, and Government owned Government operated (GOGO) arsenals providing components that will become an integral part of an ammunition round. The schematic in this section depicts the type of producers involved in manufacturing ammunition.

The bulk of production, which includes small arms ammunition items, artillery and mortar rounds, bombs, and fuzes, is done by GOCO plants. Basically, ammunition plants are classified into five categories:

a. Load, Assemble, Pack (LAP)

b. Propellants and Explosives (P&E)

c. Small Arms Ammunition (SAA)

d. Metal Parts (MPTS)

e. A plant with more than one of the above categories or multi-product use.

The types of contracts awarded to a plant vary. The LAP, P&E, SAA and multi-purpose plants operate under a cost-reimbursable contract with either fixed or incentive fee. The MPTS plants operate under a firm-fixed-price contract.

Because there is no single producer of the components that are used in the ammunition market, estimating the price is difficult. Consequently, the likelihood of incurring many different price combinations exists. For example, assume that 15 manufacturers are capable of producing components needed for a specific ammunition round. Using various combinations of producers can result in 288 different price combinations. Price combinations and the uncertainty of when inventory costs were incurred make it difficult to estimate the exact price of an ammunition round. Certain components may be procured two years before becoming an integral part of the round. The complete cost for the end item can be determined only when consideration is given to costs incurred by all producers involved in the manufacturing process. It is for this reason that individual components have been costed separately in this study.

The productive orientation of ammunition at the component level influences this project and other estimators in both the IPF and production costs.

In the IPF area the industrial production base for mobilization is established, maintained, modernized and expanded on the bases of component demand. The completed round is important only to the extent that it contributes, along with other total rounds, to the demand of the particular component. The Army does not provide TNT capacity for the M1 105mm HE howitzer projectile. Capacity is based upon total TNT demand. The consequences of this special consideration are that the preparer of cost models or IPCE's must make certain that the IPF involved considers the marginal increase in capacities and does not duplicate capacities that are already available in the industrial production base for ammunition.

In the production cost area these special considerations probably have the largest impact on the cost estimator. First, the data collection problems are greatly complicated because many manufacturers may have produced a component within a given round. Second, assuming that the first collective problem is solved and the data are cross referenced and properly normalized for inflation, the estimator must determine the most likely learning rate from a myriad of manufacturers, producing over widely varying time periods and output rates. Finally, the estimating procurement method cannot possibly be duplicated in reality when the ammunition is finally procured because of the artificiality of the estimating assumptions. The following portions of section III should be read in light of these special procurement considerations.

B. NONRECURRING INVESTMENT

The nonrecurring investment cost elements, for which equations are provided in the IPF cost model, are shown in Table III-1. In addition to the total nonrecurring investment cost, the model provides for the calculation of each of the cost elements shown in the table, including industrial production equipment (IPE), initial tooling, and test and measuring equipment for each of the ammunition components shown. All costs are in thousands of FY 74 or FY 75 constant dollars.

The IPF cost model presented herein would normally be used to estimate costs based on the mobilization requirements rather than peacetime requirements. This overstates the IPF requirements and costs for peacetime production, but satisfies the conditions dictated by the mobilization base plan.

The model is structured so that computer programing can provide for separate calculation of the estimated costs of initial tooling and test and measuring equipment, to the exclusion of IPE. This is predicated on the basis that, for a given ammunition program, the Government will not buy capital equipment but will incur costs for special tooling and gages unique to the ammunition being procured.

HIGH EXPLOSIVE COMPLETE AMMUNITION ROUND

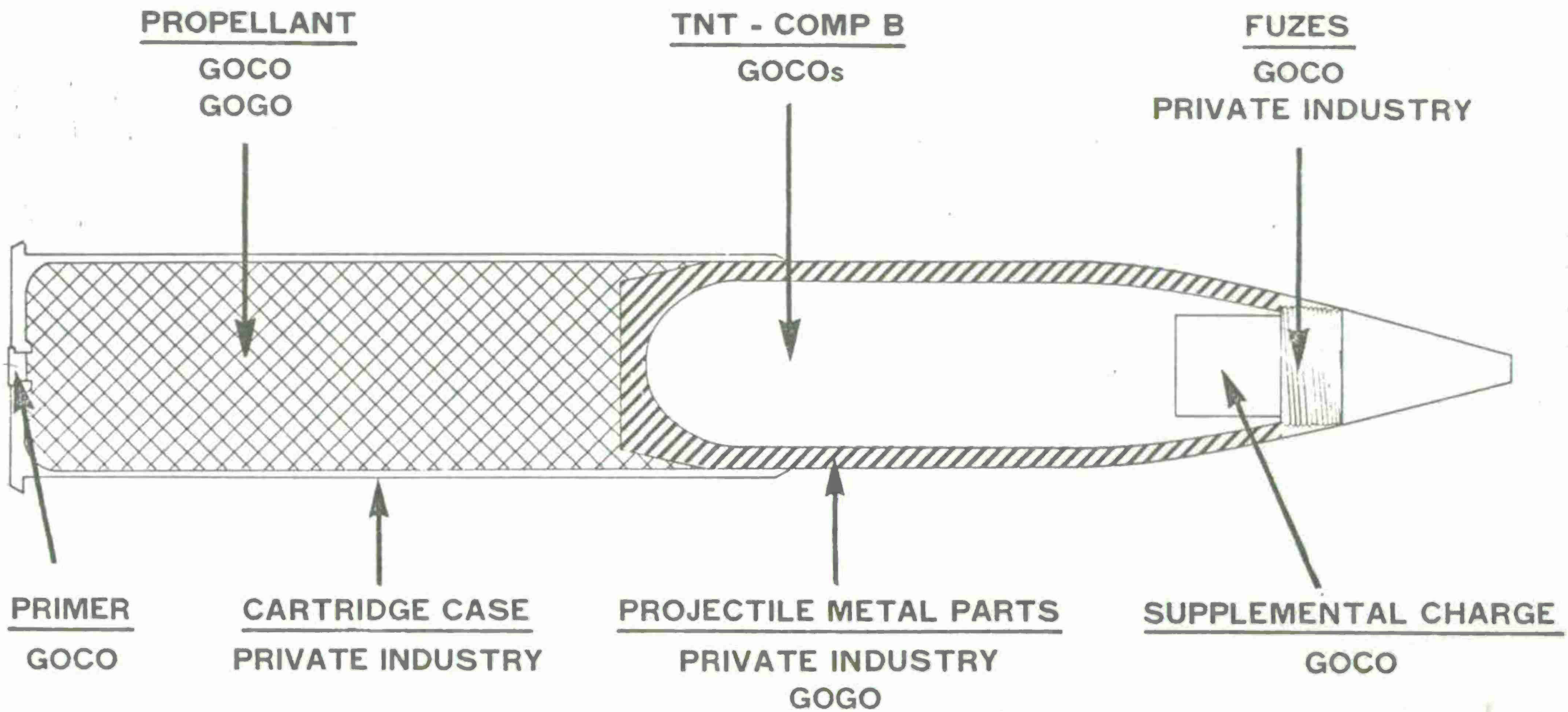

TABLE III-1

NONRECURRING INVESTMENT COST ELEMENTS

Medium Bore: Alternative A

<u>20mm-30mm</u>

IPE
1. Projectile (HEIT, APT, TPT, and APSSDS)
2. Link
3. Box
4. LAP
5. Cartridge Case (Steel and Aluminum)
6. Fuze

Initial Tooling
1. Projectile (HEIT, APT, TPT, and APSSDS)
2. Link
3. Box
4. LAP
5. Cartridge Case (Steel and Aluminum)

<u>Over 30mm-60mm</u>

IPE
1. Projectile (HET, APT, and TPT)
2. LAP
3. Cartridge Case (Steel)
4. Fuze

Initial Tooling
1. Projectile (HET, APT, and TPT)
2. LAP
3. Cartridge Case (Steel)

Medium Bore: Alternative B

<u>20mm-40mm</u>

IPE
1. Projectile (HEIT, APT, and TPT)
2. Link
3. Box
4. LAP
5. Cartridge Case (Steel and Aluminum)
6. Fuze

Initial Tooling
1. Projectile (HEIT, APT, and TPT)
2. Link
3. Box
4. LAP
5. Cartridge Case (Steel and Aluminum)
6. Fuze

Tank Main Armament

Over 60mm-152mm

IPE

1. Projectile (HET, APT, and TPT)
2. LAP (Metal and combustible cartridge cased)
3. Cartridge Case (Steel, spiral wrap, brass, and combustible)
4. Fuze

Initial Tooling

1. Projectile (HET, APT, and TPT)
2. LAP (Metal cartridge cased)
3. Cartridge Case (Steel, spiral wrap, brass, and combustible)
4. Fuze

1. Assumptions and Constraints

a. The initial production facilities (IPF) model excludes certain costs which may be incurred on a given ammunition program, but remain for the individual estimator to resolve as required. These are as follows:

(1) The model assumes no new construction - This element includes the costs of real property construction (buildings, utility systems, installed building equipment, etc.), real estate acquisition and/or improvements, and other production base support activities under the cognizance of the Corps of Engineers; and non-production equipment such as office machines and equipment. Therefore, the model is confined to IPF as defined in section 2 below.

(2) The model assumes propellants and explosives (P&E) are available The IPF portion of the Army's industrial production base is established, maintained, modernized, and expanded on the basis of component demand. The completed round is important only to the extent that it contributes, along with other total rounds, to the demand for the particular components. For example, the Army does not provide TNT capacity for a specific HE projectile; rather, capacity is based upon total TNT demand. This is a different situation than IPF for metal parts production and complete-round LAP, where discrete production bases are required in support of components for a specific family of rounds. The consequence of this special consideration is that the estimator must make certain that the industrial plant equipment (IPE) involved reflects the marginal increase in capacities and does not duplicate available, uncommitted capacities. Owing to this marginality, the various P&E items and combinations thereof, and the multitude of planned modernization and expansion projects, the P&E area has been excluded from the current model.

(3) The model assumes the acquisition of all new capital equipment, a worst case condition for all but one component (depleted uranium penetrator) The model is intended to be used very early in an items life cycle (LC); i.e., the conceptual phase. It covers the cost elements of IPE, special initial tooling, and test and measuring equipment. The model is versatile to the extent that separate estimates can be obtained for the last two elements if, this early in the items LC, the estimate guidance precludes the inclusion of IPE. This, obviously, implies the existence of a coordinated effort between the appropriate agencies. The model assumes a worst case condition from which the estimator may deviate via changing the data base, subroutines, new models, etc.; but here again, judiciousness is imperative due to the LC position of the estimate.

(4) The model does not address material handling/control systems - The specific plant layout, and the production rate, quantity, and physical bulk of the ammunition components being produced have, singly or in combination, a significant impact on the selection of this type of equipment. The equipment could vary from very simple (almost none) to very special (approaching fully automated handling). A general-purpose model intended to be applicable early in the system life cycle over a potentially wide range of the foregoing conditions, would require a series of subroutines to reflect varying degrees of equipment/control system automation. These have not been developed, but are under consideration for a future study. However, an allowance for miscellaneous material handling equipment is included in the LAP IPF model.

b. The matrices presented for IPF are founded on the following:

(1) A working shift is eight hours per day, five days per week (1-8-5).

(2) Equipment capacities, based upon the practices and efficiencies depicted in the descriptions of manufacture (ref 1 is typical), are assumed to be currently valid, except where specific process elements were known to be obsolete. In these instances an appropriate change was made.

(3) There is no reduction in unit price for capital equipment due to a quantity buy. There generally is a reduction in unit price for tooling due to a quantity buy.

c. Although the IPF model is based on established processes and equipment currently available on the market, it is not intended to represent any facility either proposed or currently in operation. However, the manufacturing processes shown are similar to the equivalent processes described in the references (ref 1 is typical).

d. The model is intended to provide IPF estimates in support of decision making early in the acquisition phase. It is not intended to be used for budget/program estimates or for production planning purposes.

e. The model makes no provision for standby production equipment to preclude line shutdown in the event of equipment breakdown. Additionally, no allowance is made for preventive maintenance.

f. For very high or very low production rates, as compared to historical requirements for camparable components and sizes, it is recommended that the estimator verify the adequacy of the production methods reflected in the model with appropriate ammunition production base personnel.

g. The model generates a parametric estimate driven by known or assumed component overall dimensions, and does not reflect the impact of discrete design detail.

h. The model contains no stated upper or lower limits for dimensions other than caliber. However, practical considerations of production methods and equipment requirements will constrain useful application of the model to ammunition that is appropriate for the specified calibers and types of ammunition listed in the data base.

i. That climatic control equipment necessary to the manufacturing and LAP of combustible cartridge case ammunition is not included in the model and is considered to be accountable to new construction (building) costs.

j. All costs are identified to FY 74 or FY 75 constant dollars.

2. Definitions

a. Line-of-balance: That array of capital equipment necessary to produce a given quantity of a specific item or product.

b. Initial Production Facilities (IPF): For the purpose of this study, IPF is defined to include only the following: capital equipment, also referred to as industrial plant equipment (IPE), tooling, test and measuring equipment (TME), layaway cost, installation cost, and transportation cost.

c. Capital Equipment: Plant equipment with an acquisition cost of $1,000 or more, involved in manufacturing operations for the purpose of cutting, grinding, shaping, joining, heating, treating, or otherwise altering the physical, electrical or chemical properties of materials, components or end items; e.g., a 200 ton hydraulic press.

d. Tooling: An item fitted to a unit of capital equipment for the purpose of imposing a specific configuration to some item of material, a component or end item; e.g., a form die to be used on a 200 ton hydraulic press. Also included are the appropriate jigs and fixtures.

e. Test and Measuring Equipment (TME): Process inspection gages and specialty equipment (i.e., X-ray equipment), and two sets of inspection and acceptance gages.

3. Medium-Bore

a. Alternative A: 20mm-60mm

(1) 20mm-30mm

(a) Industrial Plant Equipment (IPE)

The IPE (machine tools and processing equipment) required for the manufacture of a 20-30mm ammunition family is shown in Tables III-2 through III-11. The equipment lists were synthesized in a previous study, reference 49, by analyzing the manufacturing processes necessary to produce this ammunition. An adjustment factor of 1.12 was used to inflate equipment unit costs from FY 73 dollars to FY 74 dollars. It was developed from a detailed review of the production base support procurement requisition order numbers (PRONS) for FY 74 on ARMCOM projects. The price changes on the PRONS indicate a change of 12 percent through the fiscal year. In addition to the equipment costs obtained from Tables III-2 through III-11, the cost model selectively includes allowances for test and measuring equipment, transportation, installation, and layaway costs. The tables also include special initial tooling costs for each equipment item. Initial tooling required by the IPE was developed by analyzing the manufacturing processes and equipment requirements, and was inflated from FY 73 dollars to FY 74 dollars.

Tables III-2 through III-11 constitute matrices from which cost values and equipment capacities required for solution of the cost equations are selected. The notation used in the cost equations applies to each matrix. Since the cost of a fuze line is provided at the summary (total line) level, there is no matrix for fuzes. The explanations given below include the notation for initial tooling. The over 30-60mm sizes use the same notation as the 20-30mm group, but they also employ additional notation unique to the model for ammunition sizes over 30-60mm.

Subscripts

i is a matrix row: a specific item of equipment and associated initial tooling.

j is a matrix column: it refers either to equipment unit cost, annual equipment capacity per shift, or average unit initial tooling cost.

k is the specific matrix: e.g., when k=1, the HEIT Projectile matrix, Table III-2, is specified.

t a conditional code specifying CER's for APSSDS projectiles, with or without tracer cavities, to equipment or initial tooling cost catagories.

Symbols

C_k is the number of working shifts assumed in the estimate for the ammunition component identified by the value of k, where a shift is eight hours per day, five days per week (1-8-5). When one shift is assumed, C_k is given the value of 1; similarly, $C_k=2$ and $C_k=3$ for two and three shifts, respectively. An additional adjustment to the value of C_k can be made if the estimate is to be based on a working shift other than eight hours per day and/or five days per week. For example, if the shift desired is 2-8-6, $C_k=2\ (6/5)=2.4$; or, for a 2-10-5 shift, $C_k=2\ (10/8) = 2.5$.

Q_k is the annual production quantity of the ammunition component specified by the value of k in millions.

$X_{i,j,k}$ is the numerical value (equipment or unit initial tooling cost, or equipment capacity) located at the intersection of row i and column j of matrix k; e.g., $X_{3,2,1}$ provides the value 1.700 million rounds as the annual capacity per shift for the centerless grinder required to produce the HEIT projectile.

$N_{i,k}$ is the required quantity of the equipment item specified by row i of matrix k. In the solution of the model, this factor represents either the quantity of each equipment item or the number of sets of initial tooling associated with each equipment item. For example $N_{3,1}$ represents the number of centerless grinders, each grinder having an annual capacity of $C_1 X_{3,2,1}$ rounds, required to produce Q_1 HEIT projectiles. This value is rounded to the next larger integer (number of whole equipment items). For example, if the cost equation for $N_{i,k}$ yields a value of 2.005, then $N_{i,k}$ is rounded to 3.

$Y_{i,k}$ is the total cost in thousands of dollars of the equipment item specified by row i of matrix k, or its associated initial tooling; it is a function of $N_{i,k}$ and $X_{i,j,k}$.

Symbols

Y_k is the total cost in thousands of dollars of the equipment, or its associated initial tooling, needed to meet production requirements of the ammunition component specified by the value of k. It represents the summation of previously-calculated values of $Y_{i,k}$.

When applied to IPE, it includes the selective allowances for transportation, installation, layaway, and miscellaneous material handling equipment.

T_k is the total cost in thousands of dollars of test and measuring equipment (TME) required for the component specified by the value of k.

T as defined by T_k, not related to any matrix, and as further defined where used.

$T_{i,k}$ the total cost for TME requred at equipment item i of matrix k.

$NS_{i,k}$ as defined for $N_{i,k}$ but exclusive to the sabot portion of the armor piercing spin stabilized discarding sabot projectile (APSSDS).

$NT_{i,k}$ as defined for $N_{i,k}$ but exclusive to the tungsten alloy penetrator portion of the APSSDS projectile.

$YS_{i,k}$ as defined for $Y_{i,k}$ but exclusive to the sabot portion of the APSSDS projectile.

$YT_{i,k}$ as defined for $Y_{i,k}$ but exclusive to the tungsten alloy penetrator portion of the APSSDS projectile.

YS_k as defined for Y_k but exclusive to the sabot portion of the APSSDS projectile.

YT_k as defined for Y_k but exclusive to the tungsten alloy penetrator portion of the APSSDS projectile.

YU is the total additional cost, in thousands of dollars, to modify production lines already in existence to meet depleted uranium (DU) penetrator production requirements for APSSDS projectiles, or its associated initial tooling.

Symbols

YST — the total cost of all items of equipment, or its associated initial tooling, necessary to meet the APSSDS projectile (with tungsten alloy penetrator) production requirements.

YSU — the total cost of all items of equipment, or its associated initial tooling, necessary to meet the APSSDS projectile (with DU penetrator) production requirements.

R — is the number of rounds per metal ammunition box known or assumed for the estimate.

P — is the multiplier representing the percent increase in the tooling cost due to an increase in the ammunition box volume.

Using the foregoing notations, the cost equations by ammunition component are as follows:

1. Projectile

HEIT, APT, and TPT (k=1, 2, and 3, respectively)

$$N_{i,k} = \frac{Q_k}{C_k X_{i,2,k}} \qquad [1]$$

where: $N_{i,k}$ = the required equipment item quantity as previously defined, rounded to the next larger integer; e.g., if $Q_k \div C_k X_{i,2,k} = 2.005$, then $N_{i,k}$ is rounded to 3.

Q_k = annual production-quantity requirement as previously defined. NOTE: Q_1 (HEIT projectile), Q_2 (APT projectile), and Q_3 (TPT projectile) represent unique input variables.

C_k = the assumed number of shifts.

$X_{i,2,k}$ = the annual capacity per shift of equipment item i in matrix k.

$$Y_{i,k} = N_{i,k} X_{i,1,k} \qquad [2]$$

where: $Y_{i,k}$ = the total cost of equipment item i used to produce the component k.

SYMBOL

$N_{i,k}$ = value from equation [1].

$Y_{i,1,k}$ = unit cost of equipment item i used to produce the component k.

$$Y_k = \sum Y_{i,k}(1.155) + T_k \qquad [3]$$

where: Y_k = the total cost of all equipment items necessary to meet the production requirements of each projectile plus the cost of test and measuring equipment.

$Y_{i,k}$ = values from equation [2].

1.155 = 1.1(1.05), an additional 5 percent allowance for transportation and installation, and 10 percent for layaway costs. NOTE: The transportation and installation allowances were provided by the US Army Production Equipment Agency. The layaway allowance was provided by the Industrial Management Division of the Procurement and Production Directorate at ARMCOM. It consists of 6 percent for preservation and 4 percent for crating, handling, and transportation. If layaway is on the site, only the 6 percent factor is applicable; however, the 10 percent factor is used in the model to yield a conservative estimate based upon the assumption that on-site layaway versus plant clearance is not known at the time that the estimate is being made.

T_k = Total cost of test and measuring equipment (TME), and is equal to 24.0 for k=1 and 2, and 22.5 for k=3.

APSSDS (Sabot, k=4; penetrator k=5 or CER)

The armor piercing spin stabilized discarding sabot (APSSDS) projectile is made up of two components which must be separately estimated and then summed to arrive at the total estimated cost for the complete projectile IPE. These components are the sabot and the penetrator. Furthermore, there is the option of furnishing equipment to produce projectiles with or without tracer capability. The latter would be used when it was known or assumed that there would never be a requirement for tracer capability. The matricies and CER's cover a 20mm through 35mm size range, and yield estimated costs in FY 75 dollars.

$$NS_{i,4} = \frac{Q_4}{C_4 X_{i,j,4}} \qquad [4]$$

where: $NS_{i,4}$ = the required equipment item quantity, needed to produce the sabot, rounded to the next larger integer.

Q_4 = The annual production quantity requirement.

C_4 = The assumed number of shifts.

$X_{i,j,4}$ = The annual capacity per shift of equipment item i used to produce sabots. NOTE: i ranges from 1 through 13 when tracer capability is not required, and 1 through 15 when it is required.

j=2 for 20mm
j=3 for over 20-25mm
j=4 for over 25-30mm
j=5 for over 30-35mm

$$YS_{i,4} = NS_{i,4}X_{i,1,4} \qquad [5]$$

where: $YS_{i,4}$ = The total cost of equipment item i. NOTE: i ranges from 1 to 13 without tracer, and 1 to 15 with tracer.

$NS_{i,4}$ = The value from equation [4].

$X_{i,1,4}$ = The unit cost of equipment item i.

$$YS_4 = \sum YS_{i,4}(1.155) + T_4 \qquad [6]$$

where: YS_4 = The total cost of all items of equipment necessary to meet the sabot production requirement, plus the cost of test and measuring equipment.

$YS_{i,4}$ = The values from equation [5], and as limited by i.

1.155 = 1.1(1.05), an additional 5 percent allowance for transportation and installation, and 10 percent for layaway costs.

T_4 = 19.5 for TME.

$$NT_{i,5} = \frac{Q_5}{C_5X_{i,j,5}} \qquad [7]$$

where: $NT_{i,5}$ = The required equipment item quantity, needed to produce tungsten penetrator, rounded to the next larger integer.

Q_5 = The annual production quantity requirement.

C_5 = The assumed number of shifts.

$X_{i,j,5}$ = The annual capacity per shift of equipment item i used to produce tungsten alloy penetrators. NOTE: i ranges from 1 through 7 when tracer capacity is not required, and 1 through 8 when it is required.

j=2 for 20mm
j=3 for over 20-25mm
j=4 for over 25-30mm
j=5 for over 30-35mm

$$YT_{i,5} = NT_{i,5}X_{i,1,5} \quad [8]$$

where: $YT_{i,5}$ = The total cost of equipment item i. NOTE: i ranges from 1 to 7 without tracer, and 1 to 8 with tracer.

$NT_{i,5}$ = The value from equation [7].

$X_{i,1,5}$ = The unit cost of equipment item i.

$$T_{i,5} = X_{i,8,5} + NT_{i,5}X_{i,9,5} \quad [9]$$

where: $T_{i,5}$ = The total cost for test and measuring equipment (TME) required at equipment item i of matrix k=5 and as limited by i.

$X_{i,8,5}$ = A one time cost for TME.

$NT_{i,5}$ = The value from equation [7].

$X_{i,9,5}$ = The unit cost of in process TME.

$$T_5 = \sum T_{i,5} \quad [10]$$

where T_5 = The total cost of all TME required to meet production requirements of the ammunition component specified by the value of k, and as limited by i.

$T_{i,5}$ = The value from equation [9].

$$YT_5 = \sum YT_{i,5}(1.155) + T_5 \quad [11]$$

where: YT_5 = The total cost of all items of equipment necessary to meet the tungsten alloy penetrator production requirements, plus the cost of test and measuring equipment.

$YT_{i,5}$ = The value from equation [8], and as limited by i.

1.155 = 1.1(1.05), an additional 5 percent allowance for transportation and installation, and 10 percent for layaway costs.

T_5 = The value from equation [10], and as limited by i.

Depleted Uranium Alloy Penetrator (DU)

Most of the detailed data available, especially that related to yields, capacities, etc., from National Lead of Ohio (NLO), are classified confidential (restricted) by the Energy Research and Development Agency. Therefore, the data and resultant CER's below do not yield "worst case" conditions which are otherwise typical throughout the IPF portion of this study. They do not apply to the establishment of a new facility, but reflect only the additional costs necessary to modify production lines already in existence at the GOCO manufacturing facility at NLO.

The estimated costs for additional capital equipment and tooling, identified as actual cost in the CER data displayed below, are for a generic 25mm Vehicle Rapid Fire Weapon System (VRFWS) armor piercing, spin stabilized, discarding sabot (APSSDS) projectile, and are based on 30mm GAU-8 data obtained from NLO. Independent estimates were then developed for 20mm, 30mm, and 35mm penetrators of similar design. Also, the estimates identify penetrators as being with or without tracer cavities.

The cost equation and CER's, expressed in FY 75 dollars, are:

$$YU = 1.155 \text{ Antiln } Z_t + T \qquad [12]$$

where: YU = The total additional cost to modify production lines already in existence to meet DU penetrator production requirements, plus the cost of TME.

Antiln Z_t = The estimated additional IPE costs, where t=1 and t=2, represent the DU penetrator with (equation [12.1]) or without (equation [12.2]) tracer cavities.

1.103 = 1.1(1.05), an additional 5 percent allowance for transportation and installation, and 10 percent for layaway costs.

T = The total cost of TME is assumed to be zero, since only <u>additional</u> IPE and tooling are estimated and the TME is <u>considered</u> to already be on site.

CER for DU Penetrator
With Tracer Cavity

$$\ln Z_1 = 4.0188 + 0.5406 \ln X + 0.3547\ Y \qquad [12.1]$$

where: Z_1 = Estimated additional IPE cost in FY 75 thousand dollars.

X = Full-bore size in millimeters.
Y = Annual production rate in millions.

Statistics:
Coefficients of determination
Multiple = 0.942
Partial
ZX.Y = 0.419
ZY.X = 0.940
XY = 0.000
Standard error of estimate in Ln form = 0.147
Mean absolute percent deviation = 11.5
Passes F test at 99 percent level of confidence
N = 16

CER DATA

Full-Bore Size(mm)	Production Rate Per Year (M)	Actual Cost (K)	Estimated Cost (K)
20	0.312	$ 352.2	$ 313.9
20	0.832	352.2	377.4
20	2.080	700.6	587.6
20	4.160	1,076.0	1,228.9
25	0.312	325.2	354.1
25	0.832	515.4	425.8
25	2.080	705.6	663.0
25	4.160	1,266.2	1,386.4
30	0.312	330.2	390.8
30	0.832	520.4	469.9
30	2.080	895.8	731.6
30	4.160	1,456.4	1,530.0
35	0.312	335.2	424.7
35	0.832	525.4	510.8
35	2.080	900.8	795.2
35	4.160	1,646.6	1,663.0

CER for DU Penetrator
Without Tracer Cavity

$$\mathrm{Ln}Z_2 = 3.8864 + 0.4649\ \mathrm{Ln}X + 0.2848\ Y \qquad [12.2]$$

where: Z_2 = Estimated additional IPE cost in FY 75 thousand dollars.

X = Full-bore size in millimeters.
Y = Annual production rate in millions.

Statistics:
Coefficients of determination
Multiple = 0.955
Partial
ZX.Y = 0.518
ZY.X = 0.953
XY = 0.000
Standard error of estimate in Ln form = 0.104
Mean absolute percent deviation = 8.1
Passes F test at 99 percent level of confidence
N = 16

CER DATA

Full-Bore Size(mm)	Production Rate Per Year (M)	Actual Cost (K)	Estimated Cost (K)
20	0.312	$225	$214.4
20	0.832	225	248.7
20	2.080	400	354.8
20	4.160	575	641.5
25	0.312	225	237.9
25	0.832	315	275.8
25	2.080	405	393.6
25	4.160	665	711.7
30	0.312	230	258.9
30	0.832	320	300.2
30	2.080	495	428.4
30	4.160	755	774.6
35	0.312	235	278.1
35	0.832	325	322.5
35	2.080	500	460.2
35	4.160	845	832.2

$$YST = \left[\sum YS_{i,4} + \sum YT_{i,5}\right] (1.155) + T_4 + T_5 \qquad [13]$$

where: YST = The total cost of all items of equipment necessary to meet the APSSDS projectile with tungsten alloy penetrator production requirements, plus the cost of TME, and as limited by i.
All other values are as provided by equations [6] and [11].

$$YSU = \left[\sum YS_{i,4} + \text{Antiln } Z_t\right] (1.155) + T_4 + T \qquad [14]$$

where: YSU = The total cost of all items of equipment necessary to meet the APSSDS projectile with depleted uranium (DU) penetrator production requirements, plus the cost of TME, and as limited by i.
All other values are as provided by equations [6] and [12].

2. Link (k=6)

$$N_{i,6} = \frac{Q_6}{C_6 X_{i,2,6}} \qquad [15]$$

where: $N_{i,6}$ = The required equipment item quantity rounded to the next larger integer.

Q_6 = The annual production quantity requirement and is the sum of Q_1, Q_2, Q_3, and Q_4, or is set equal to zero if

link-production equipment is assumed to be in existence or is otherwise not required.

C_6 = The assumed number of shifts.

$X_{i,2,6}$ = The annual capacity per shift of equipment item i used to produce links.

$$Y_{i,6} = N_{i,6} X_{i,1,6} \qquad [16]$$

where: Y_6 = The total cost of equipment item i used to produce links.

$N_{i,6}$ = The value from equation [15].

$X_{i,1,6}$ = The unit cost of equipment item i used to produce links.

$$Y_6 = \sum Y_{i,6}(1.155) + T_6 \qquad [17]$$

where: Y_6 = The total cost of all equipment items necessary to meet link production requirements, plus the cost of TME.

$Y_{i,6}$ = Values from equation [16].

1.155 = 1.1(1.05), an additional 5 percent allowance for transportation and installation, and 10 percent for layaway costs.

T_6 = 26.9 for TME.

3. Box (k=7)

$$N_{i,7} = \frac{100Q_7}{C_7 X_{i,2,7} R} \quad [18]$$

where: $N_{i,7}$ = the required equipment item quantity rounded to the next larger integer.

Q_7 = $Q_1+Q_2+Q_3+Q_4$, the annual box production-quantity requirement, expressed in millions of rounds. (See note, bottom of Table III-8); Q_7 is set equal to zero if box-production equipment and tooling are assumed to be in existence or is otherwise not required.

C_7 = the assumed number of shifts.

$X_{i,2,7}$ = the annual capacity per shift of equipment item i in matrix k where k=7. This is expressed in millions of rounds.

R = the number of rounds per box known or assumed for the estimate. See Note below.

100 = the number of rounds per box assumed in establishing the matrix k=7.

$$Y_{i,7} = N_{i,7} X_{i,1,7} \quad [19]$$

where: $Y_{i,7}$ = the total cost of equipment item i used to produce ammunition boxes.

$N_{i,7}$ = the value from equation [18].

$X_{i,1,7}$ = the unit cost of equipment item i used to produce ammunition boxes.

$$Y_7 = \sum Y_{i,7}(1.155) + T_7 \quad [20]$$

where: Y_7 = the total cost of all equipment items necessary to meet ammunition box production requirements, plus the cost of TME.

$Y_{i,7}$ = the values from equation [19].

1.155 = 1.1(1.05), an additional 5 percent allowance for transportation and installation, and 10 percent for layaway costs.

T_7 = 10.5 for TME.

NOTE: To aid the estimator in determining a value for R, the following is offered: The 100 rounds per box assumed above is based on 100 rounds of M246, HEIT, 20mm, linked ammunition which weighs 69 pounds. The box is the M548 or an equivalent. The M548 box packed out (packing material and 100 rounds of linked M246) weighs 91 pounds. If the estimator knows the weight of the linked ammunition he is dealing with, he can divide its unit weight into 69 pounds to determine how many rounds of ammunition he can get in a box.

If the estimator is interested in bulk packed rather than linked ammunition, the following may be used: The M548 ammunition box will hold 200 rounds of the M246 unlinked; its packed out weight is 141 pounds and the 200 rounds of ammunition weighs 114 pounds. To determine the number of rounds that would fit into this box, proceed as above. The preceding assumes that the weight is reasonably proportional to the volume.

As a precaution, it is suggested that the estimator determine the volume (in cubic feet) of the quantity (R value) determined above and compare it to the available volume in the M548 ammunition box. This is to preclude the mis-stating of box capacity; since, if the round has an aluminum cartridge case in lieu of steel and/or a discarding sabot projectile in lieu of a convention projectile, the volume would not be reasonably proportional to the weight.

The internal dimensions of the M548 box are 17-1/4" x 7-7/16" x 13-63/64" with a volume of 1.038 cubic feet. This volume can be increased by fifty percent, to 1.557 cubic feet, without having any significant effect on the capital equipment's cost or capacity. For this fifty percent increase in volume it may be necessary to increase the tooling cost by approximately twenty percent.

4. LAP (k=8)

Equations [1] and [2] apply to the LAP equipment, with the subscript k=8, and $Q_8 = Q_1 + Q_2 + Q_3 + Q_4$. The total cost summation equation for LAP equipment is as follows:

$$Y_8 = \sum Y_{i,8}(1.2705) + T_8 \qquad [21]$$

where: Y_8 = the total cost of all items of equipment required to LAP the ammunition components, plus the cost of TME.

$Y_{i,8}$ = the values from equation [2] applied to the LAP matrix, Table III-9 (k=8).

1.2705 = 1.1(1.155), a 10 percent allowance for miscellaneous material handling equipment applied in addition to the allowances previously defined.

T_8 = 38.5 for TME.

5. Cartridge Case

Steel (k=9)

$$N_{i,9} = \frac{Q_9}{C_9 X_{i,3,9}} \qquad [22]$$

where: $N_{i,9}$ = the required equipment item quantity rounded to the next larger integer.

Q_9 = $Q_1 + Q_2 + Q_3 + Q_4 = Q_8$, the annual production quantity requirement.

C_9 = the assumed number of shifts.

$X_{i,3,9}$ = the annual capacity per shift of equipment item i used to produce cartridge cases.

Alternative choices of equation [23] below are based on a variation in the number of drawing operations and the press tonnages required for the blanking and drawing operations, depending on the ratio of length to diameter of the cartridge case being estimated. The former variation is accounted for by the addition of equipment items 25 and 26 (4th draw and 4th draw trim) in Table III-10; whereas the latter variation is accounted for by variations in affected press tonnages and the addition of a second column of equipment unit costs (j=2) to Table III-10 to accommodate the higher tonnages. Under conditions a, b, and c, below, L is the total length of the case in inches, and D is the projectile diameter in millimeters.

a. $L \leq 3.5$ in., $D \leq 30$mm, i = 1, 2, ..., 24

$$Y_{i,9} = N_{i,9} X_{i,1,9} \qquad [23.1]$$

where: $Y_{i,9}$ = the total cost of equipment item i used to produce cartridge cases.

$N_{i,9}$ = the values from equation [22].

$X_{i,1,9}$ = the unit cost of equipment item i used to produce cartridge cases.

b. $L > 3.5$ in., $D = 20$mm, i = 1, 2, ..., 26

$$Y_{i,9} = N_{i,1,9} X_{i,1,9} \qquad [23.2]$$

where all factors are as defined in paragraph a, above.

c. $L > 3.5$ in., $20\text{mm} < D \leq 30$mm, i = 1, 2, ..., 26.

$$Y_{i,9} = N_{i,9} X_{i,2,9} \qquad [23.3]$$

where all factors are as defined in paragraph a, above.

d. Summation equation for conditions a, b, c:

$$Y_9 = \sum Y_{i,9}(1.155) + T_9 \qquad [24]$$

where: Y_9 = the total cost of all items of equipment necessary to meet steel cartridge case production requirements, plus the cost of TME.

$Y_{i,9}$ = the values from appropriate conditional equation [23].

1.155 = 1.1(1.05), an additional 5 percent allowance for transportation and installation, and 10 percent for layaway costs.

T_9 = 54.5 for TME.

Aluminum (k=10)

The matrix for aluminum cartridge cases covers a 20mm through 35mm size range. Those data are based upon reference 93 and unpublished, Frankford Arsenal, in-house studies. Costs are expressed in FY 74 dollars.

$$N_{i,10} = \frac{Q_{10}}{C_{10}X_{i,2,10}} \qquad [25]$$

where: $N_{i,10}$ = the required equipment item quantity rounded to the next larger integer.

Q_{10} = $Q_1 + Q_2 + Q_3 + Q_4 = Q_8$, the annual production quantity requirement.

C_{10} = the assumed number of shifts.

$X_{i,2,10}$ = the annual capacity per shift of equipment item i used to produce cartridge cases.

$$Y_{i,10} = N_{i,10}X_{i,1,10} \qquad [26]$$

where: $Y_{i,10}$ = the total cost of equipment item i used to produce cartridge cases.

$N_{i,10}$ = the value from equation [25].

$X_{i,1,10}$ = the unit cost of equipment item i used to produce cartridge cases.

$$Y_{10} = \sum Y_{i,10}(1.155) + T_{10} \qquad [27]$$

where: Y_{10} = the total cost of all items of equipment necessary to meet aluminum cartridge case production requirements, plus the cost of TME.

$Y_{i,10}$ = the value from equation [26].

1.155 = 1.1(1.05), an additional 5 percent allowance for transportation and installation, and 10 percent for layaway costs.

T_{10} = 19.4 for TME.

6. Fuze Line

$$N = \frac{Q}{1.2C} \qquad [28]$$

where: N = the number of fuze lines required to meet annual production quantity requirements, rounded to the next larger integer.

Q = Q_1, the annual production quantity requirement.

C = the assumed number of shifts.

1.2 = a constant annual production capacity per fuze line per shift expressed in millions.

$$Y = N(1,786)\ (1.10) + T \qquad [29]$$

where: Y = the total cost of the fuze line(s) required to meet fuze-production requirements, including layaway cost, plus the cost of TME.

N = the value from equation [28].

1,786 = the average unit cost per fuze line, expressed in thousands of dollars, comprised of capital equipment, initial tooling, and transportation and installation costs, but excluding layaway cost.

1.10 = an additional 10 percent allowance for layaway cost.

T = 178.6 for TME.

(b) Initial Tooling

This cost element covers the special initial tooling required for the IPE items shown in Tables III-2 through III-11 covering projectiles, links, boxes, LAP, and cartridge cases. The number of sets of initial tooling required for each equipment item i of each matrix is the same as the corresponding equipment item i quantity previously calculated using the IPE cost equations in section IIIB.3.a.(1).(a). (No tooling is required for fuzes.) This quantity is expressed for IPE quantities as $N_{i,k}$. Given the previously calculated values of $N_{i,k}$, the resulting initial tooling cost equations are:

1. Projectile

HEIT, APT, and TPT (k=1, 2, and 3, respectively)

$$Y_{i,k} = N_{i,k}X_{i,j,k} \qquad [30]$$

where: $Y_{i,k}$ = the total cost of the initial tooling required for equipment item i of matrix k.

$N_{i,k}$ = the value from equation [1], as applicable for the value of k for the component being estimated.

$X_{i,j,k}$ = the average unit tooling cost for equipment item i of matrix k, where the value of subscript j = $N_{i,k}$ + 2.

$$Y_k = \sum Y_{i,k} \qquad [31]$$

where: Y_k = the total cost of all initial tooling required to meet production requirements of the ammunition component specified by the value of k.

$Y_{i,k}$ = the values from equation [30].

APSSDS (Sabot, k=4; penetrator, k=5 or CER)

$$YS_{i,4} = N_{i,4}X_{i,6,4} \qquad [32]$$

where: $YS_{i,4}$ = the total cost of the initial tooling required for equipment item i, and as limited by i.

$N_{i,4}$ = the value from equation [4].

$X_{i,6,4}$ = the average unit tooling cost for equipment item i, and as limited by i.

$$YS_4 = \sum YS_{i,4} \qquad [33]$$

where: YS_4 = the total cost of all initial tooling required to meet sabot production requirements.

$YS_{i,4}$ = the values from equation [32], and as limited by i.

$$YT_{i,5} = X_{i,6,5} + NT_{i,5}X_{i,7,5} \qquad [34]$$

where: $YT_{i,5}$ = the total cost of the initial tooling required for equipment item i, and as limited by i.

$X_{i,6,5}$ = a one-time cost of initial tooling required for equipment item i, and as limited by i.

$NT_{i,5}$ = the value from equation [7].

$X_{i,7,5}$ = the additional average unit tooling cost for equipment item i, and as limited by i.

$$YT_5 = \sum YT_{i,5} \qquad [35]$$

where: YT_5 = the total cost of all initial tooling required to meet the tungsten alloy penetrator production requirements.

$YT_{i,5}$ = the values from equation [34], and as limited by i.

$$YU = \text{Antiln } Z_t \qquad [36]$$

where: YU = the total additional cost of all initial tooling required to meet the DU penetrator requirements.

Antiln Z_t = the estimated additional tooling cost, where t=1 and t=2 represent the DU penetrator with (equation [36.1]) or without (equation [36.2]) tracer cavities.

CER for DU Penetrator With Tracer Cavity

$$\text{Ln}Z_1 = 4.6852 + 0.2221 \text{ Ln}X + 0.1409 \text{ } Y \qquad [36.1]$$

where: Z_1 = Estimated additional tooling cost in FY 75 thousand dollars.

X = Full-bore size in millimeters.
Y = Annual production rate in millions.

Statistics:
- Coefficients of determination
  - Multiple = 0.965
  - Partial
    - ZX.Y = 0.561
    - ZY.X = 0.963
    - XY = 0.000
- Standard error of estimate in Ln form = 0.046
- Mean absolute percent deviation = 3.5
- Passes F test at 99 percent level of confidence
- N = 16

CER DATA

Full-Bore Size (mm)	Production Rate Per Year (M)	Actual Cost (K)	Estimated Cost (K)
20	0.312	$231.6	$220.2
20	0.832	231.6	236.9
20	2.080	292.6	282.5
20	4.160	353.6	378.7
25	0.312	231.6	231.4
25	0.832	262.1	249.0
25	2.080	292.6	296.8
25	4.160	384.1	397.9
30	0.312	231.6	240.9
30	0.832	262.1	259.3
30	2.080	323.1	309.1
30	4.160	414.6	414.4
35	0.312	231.6	249.3
35	0.832	262.1	268.3
35	2.080	328.1	319.9
35	4.160	455.1	428.8

CER for DU Penetrator Without Tracer Cavity

$$\ln Z_2 = 4.6161 + 0.2353 \ln X + 0.1396\ Y \qquad [36.2]$$

where: Z_2 = Estimated additional tooling cost in FY 75 thousand dollars.

X = Full-bore size in millimeters.

Y = Annual production rate in millions.

Statistics:

Coefficients of determination

Multiple = 0.969

Partial

ZX.Y = 0.626

ZY.X = 0.967

XY = 0.000

Standard error of estimate in Ln form = 0.042

Mean absolute percent deviation = 3.0

Passes F test at 99 percent level of confidence

N = 16

CER DATA

Full-Bore Size (mm)	Production Rate Per Year (M)	Actual Cost (K)	Estimated Cost (K)
20	0.312	$224	$213.7
20	0.832	229	229.8
20	2.080	282	273.5
20	4.160	340	365.7
25	0.312	224	225.2
25	0.832	253	242.2
25	2.080	287	288.3
25	4.160	374	385.4
30	0.312	224	235.1
30	0.832	253	252.8
30	2.080	311	300.9
30	4.160	403	402.3
35	0.312	229	243.8
35	0.832	258	262.1
35	2.080	321	312.0
35	4.160	442	417.1

$$YST = \sum YS_{i,4} + \sum YT_{i,5} \qquad [37]$$

where: YST = The total cost of all initial tooling necessary to meet the APSSDS projectile with tungsten alloy penetrator production requirements, and as limited by i. All other values are as provided by equations [33] and [35].

$$YSU = \sum YS_{i,4} + \text{Antiln } Z_t \qquad [38]$$

where: YSU = The total cost of all initial tooling necessary to meet the APSSDS projectile with depleted uranium (DU) penetrator production requirements, and as limited by i. All other values are as provided by equations [33] and [36].

2. Link (k=6)

$$Y_{i,6} = N_{i,6}X_{i,j,6} \qquad [39]$$

where: $Y_{i,6}$ = the total cost of the initial tooling required for equipment item i.

$N_{i,6}$ = the value from equation [15].

$X_{i,j,6}$ = the average unit tooling cost for equipment item i, where the value of subscript $j=N_{i,6} + 2$.

$$Y_6 = \sum Y_{i,6} \qquad [40]$$

where: Y_6 = the total cost of all initial tooling required to meet link production requirements.

$Y_{i,6}$ = the value from equation [39].

3. Box (k=7)

$$Y_{i,7} = N_{i,7}X_{i,j,7} \qquad [41]$$

where: $Y_{i,7}$ = the total cost of the initial tooling required for equipment item i.

$N_{i,7}$ = the value from equation [18].

$X_{i,j,7}$ = the average unit tooling cost for ammunition box equipment item i, where the value of subscript $j=N_{i,7} + 2$.

$$Y_7 = \sum Y_{i,7}(P) \qquad [42]$$

where: Y_7 = the total cost of all initial tooling required to meet ammunition box production requirements.

$Y_{i,7}$ = the value from equation [41].

P = the percent adjustment upward due to increasing box size. (See note related to equation [18]).

4. LAP (k=8)

$$Y_{i,8} = N_{i,8}X_{i,j,8} \qquad [43]$$

where: $Y_{i,8}$ = the total cost of the initial tooling required for equipment item i.

$N_{i,8}$ = the value from equation [1] with subscript k=8 and directed above in equation [21].

$Y_{i,j,8}$ = the average unit tooling cost for equipment item i, where the value of $j=N_{i,6}+2$.

$$Y_8 = \sum Y_{i,8} \qquad [44]$$

where: Y_8 = the total cost of all initial tooling required to meet LAP production requirements.

$Y_{i,8}$ = the value from equation [43].

5. Cartridge Case

Steel (k=9)

The conditional cost equations for cartridge cases are as follows (same length and diameter categories as those for IPE, paragraphs III B.3.a.(1).(a).5.a. through c.):

a. $L \leq 3.5$ in., $D \leq 30$mm, i = 1, 2, ..., 24

$$Y_{i,9} = N_{i,9}X_{i,j,9} \qquad [45.1]$$

where: $Y_{i,9}$ = total cost of the initial tooling required for cartridge case equipment item i.

$N_{i,9}$ = the value from equation [22].

$X_{i,j,9}$ = the average unit tooling cost for cartridge case equipment item i, where the value of subscript $j=N_{i,9}+3$.

b. $L > 3.5$ in., $D = 20mm$, $i = 1, 2, \ldots, 26$

$$Y_{i,9} = N_{i,9}X_{i,j,9} \qquad [45.2]$$

where each variable is as defined in equation [45.1].

c. $L > 3.5$ in., $20mm < D \leq 30mm$, $i = 1, 2, \ldots, 26$

$$Y_{i,9} = 2N_{i,9}X_{i,j,9} \qquad [45.3]$$

where each variable is as defined in equation [45.1]; and factor 2 provides for doubling the initial tooling matrix value, based on the engineering judgment of Lake City Army Ammunition Plant personnel, to account for the higher cost of the heavier press tooling. (See paragraph III.B.3.a.(1).(a)5.)

d. Summation equation for conditions a, b, c:

$$Y_9 = \sum Y_{i,9} \qquad [46]$$

where: Y_9 = the total cost of all initial tooling required to meet steel cartridge case production requirements.

$Y_{i,9}$ = the value from appropriate equation [45].

Aluminum (k=10)

$$Y_{i,10} = N_{i,10}X_{i,j,10} \qquad [47]$$

where: $Y_{i,10}$ = the total cost of the initial tooling required for equipment item i.

$N_{i,10}$ = the value from equation [25].

$X_{i,j,10}$ = the average unit tooling cost for equipment item i, where the value of $j=N_{i,10}+2$.

$$Y_{10} = \sum Y_{i,10} \qquad [48]$$

where: Y_{10} = the total cost of all initial tooling required to meet aluminum cartridge case production requirements.

$Y_{i,10}$ = the value from equation [47].

(2) Over 30-60mm

(a) Industrial Plant Equipment (IPE)

The IPE required for the manufacture of an over 30mm through 60mm ammunition family is shown in Tables III-12 through III-16. The equipment lists were developed from a detailed analysis of the manufacturing processes necessary to produce the 57mm family provided in references 1 through 5. Appropriate modifications to these processes were made, so that the conventionally cased ammunition, as opposed to the recoilless-rifle family, is reflected in the equipment lists. In addition to the equipment costs obtained from Tables III-12 through III-16, the cost model selectively includes allowances in the cost equations for test and measuring equipment, transportation, installation, and layaway costs. The tables also include special initial tooling costs per equipment item. Required initial tooling was developed and costs were estimated from the detailed information presented in references 1 through 5.

Tables III-12 through III-16 constitute matrices from which the cost model selects cost values and equipment capacities required for the solution of the cost equations. Since these matrices are based on 57mm ammunition, the cost model selectively applies dimensional adjustments in the cost equations for size variations affecting equipment capacities. The notation used in the cost equations applies uniformly to each matrix and is identical to that presented previously except for the following additions:

Subscripts

c identifies cartridge case.

p identifies projectile.

Symbols

D is the projectile diameter of the ammunition family for which IPE is being estimated. Expressed in millimeters, this value ranges from over 30mm through 60mm.

L_p is the projectile length in inches.

L_c is the cartridge case length in inches.

n is the upper value of i representing the last item of equipment within the range of i values for a specific matrix k for which a dimensional adjustment to equipment capacity per shift is required because of projectile length and diameter. The values of i are taken in sequence starting with i=1.

m — is the upper value of i representing the last item of equipment within the range of i values for a specific matrix k for which a dimensional adjustment to equipment capacity per shift is required because of the projectile diameter only. The values of i are taken in sequence starting with i = n + 1.

q — is the upper value of i representing the last item of equipment within the range of i values for a specific matrix k for which a dimensional adjustment to equipment capacity per shift is not required. The values of i are taken in sequence starting with i = m + 1.

$NA_{i,k}$ — is the required quantity of the equipment item specified by row i in matrix k, where i ranges in value from 1 through n.

$NB_{i,k}$ — is the required quantity of the equipment item specified by row i in matrix k, where i ranges in value from n + 1 through m.

$NC_{i,k}$ — is the required quantity of the equipment item specified by row i in matrix k, where i ranges in value from m + 1 through q.

$YA_{i,k}$ — is the total cost in thousands of dollars of the equipment item specified by row i in matrix k, where the value of i ranges from 1 through n; it is a function of $NA_{i,k}$ and $X_{i,j,k}$.

$YB_{i,k}$ — is the same as $YA_{i,k}$, except that the value of i ranges from n + 1 through m.

$YC_{i,k}$ — is the same as $YA_{i,k}$, except that the value of i ranges from m + 1 through q.

The cost equations by component, using the foregoing notation, are as follows:

1. <u>Projectile (HET, APT, and TPT)</u> (k=11, 12, and 13, respectively)

$$NA_{i,k} = \frac{DL_p Q_k}{480\ C_k X_{i,2,k}} \qquad [49]$$

where: $NA_{i,k}$ = the required equipment item quantity as previously defined, rounded to the next larger integer; e.g., if $DL_p Q_k \div 480\ C_k X_{i,2,k} = 2.005$, then $NA_{i,k}$ is rounded to 3.

NOTE: i ranges from 1 through n.

D = the projectile diameter.

L_p = the projectile length.

Q_k = the annual production quantity requirements.

480 = 60mm times 8 inches, which represents the 60mm projectile diameter and an assumed 8-inch maximum projectile length.

NOTE: To express the upper model limits in the equipment quantity equation, a projectile diameter of 60mm is used as an estimating base rather than 57mm. True variation in required equipment quantity, caused by capacity variation with projectile diameter, is a step function. A quantity variation would not be expected between 57mm and 60mm.

C_k is the assumed number of shifts.

$X_{i,2,k}$ is the annual capacity per shift of equipment item i of matrix k.

$$NB_{i,k} = \frac{DQ_k}{60\ C_k X_{i,2,k}} \qquad [50]$$

where: $NB_{i,k}$ = the required equipment item quantity rounded to the next larger integer.

NOTE: i ranges in value from n + 1 through m.

60 = the upper model limit on projectile diameter. All other factors are as defined for equation [49].

$$YA_{i,k} = NA_{i,k} X_{i,1,k} \qquad [51]$$

where: $YA_{i,k}$ = the total cost of equipment item i.

NOTE: i ranges in value from 1 through n.

$NA_{i,k}$ = the value from equation [49].

$X_{i,1,k}$ = the unit cost of equipment item i.

$$YB_{i,k} = NB_{i,k} X_{i,1,k} \qquad [52]$$

where: $YB_{i,k}$ = the total cost of equipment item i.

NOTE: i ranges in value from n + 1 through m.

$NB_{i,k}$ = the value from equation [50].

$X_{i,1,k}$ = the unit cost of equipment item i.

$$Y_k = \left[\sum_{i=1}^{n} YA_{i,k} + \sum_{i=n+1}^{m} YB_{i,k}\right] 1.155 + T_k \qquad [53]$$

where: Y_k = the total cost of all items of equipment necessary to meet the production requirements of each projectile plus the cost of TME.

$YA_{i,k}$ = the values from equation [51].

$YB_{i,k}$ = the values from equation [52].

n = the upper value of i, as previously defined.

m = the upper value of i, as previously defined.

1.155 = 1.1(1.05), an additional 5 percent allowance for transportation and installation, and 10 percent for layaway costs.

T_k = the total cost of test and measuring equipment.

NOTE: n, m, and T_k assume the following values, dependent upon the value of k:

k	n	m	T_k
11	4	13	45.2
12	11	14	55.9
13	4	11	48.0

2. LAP (k=14)

Equations [49], [50], [51], and [52] apply to the LAP equipment, with the subscript k = 14, and $Q_k = Q_{14} = Q_{11} + Q_{12} + Q_{13}$. The following equations also apply:

$$NC_{i,14} = \frac{Q_{14}}{C_{14}X_{i,2,14}} \qquad [54]$$

where: $NC_{i,14}$ = the required equipment item quantity as previously defined, rounded to the next larger integer.

NOTE: i ranges in value from m + 1 through q. All other factors are as defined in equation [49].

$$YC_{i,14} = NC_{i,14}X_{i,1,14} \qquad [55]$$

where: $YC_{i,14}$ = the total cost of equipment item i as previously defined.

NOTE: i ranges in value from m + 1 through q.

$NC_{i,14}$ = the value from equation [54].

$X_{i,1,14}$ = as defined in equation [51].

$$Y_{14} = [\sum_{i=1}^{n} YA_{i,14} + \sum_{i=n+1}^{m} YB_{i,14} + \sum_{i=m+1}^{q} YC_{i,14}]1.2705 + T_{14} \qquad [56]$$

where: Y_{14} = the total cost of all items of equipment required to load, assemble, and pack the ammunition components, plus the cost of test and measuring equipment.

$YA_{i,14}$ = values from equation [51] with subscript k=14.

$YB_{i,14}$ = values from equation [52] with subscript k=14.

$YC_{i,14}$ = values from equation [55]. For k=14; n=8, m=11, and q = 15 and are as previously defined.

1.2705 = 1.1(1.155), a 10 percent allowance for miscellaneous material handling equipment applied in addition to the allowance previously defined.

T_{14} = 158.0 for TME.

3. Cartridge Case - Steel (k=15)

$$NA_{i,15} = \frac{DL_c Q_{15}}{720\ C_{15} X_{i,2,15}} \qquad [57]$$

where: $NA_{i,15}$ = the required equipment item quantity as previously defined, rounded to the next larger integer.

NOTE: i ranges in value from 1 through n.

D = the projectile diameter.

L_c = the cartridge case length.

Q_{15} = $Q_{11} + Q_{12} + Q_{13} = Q_{14}$, the annual production quantity requirement.

720 = 60 times 12 inches, which represents the 60mm projectile diameter and the 12 inch length of the 57mm cartridge case, the upper model limits. (See equation [49] for note relating to the 60mm upper limit.)

C_{15} = the assumed number of shifts.

$X_{i,2,15}$ = the annual capacity per shift of equipment item i used to produce cartridge cases.

Equation [50] also applies to the cartridge case equipment, when k=15, n=17, m=26, and Q_{15} is as defined for equation [57]. The following equation also applies:

$$NC_{i,15} = \frac{Q_{15}}{C_{15}X_{i,2,15}} \qquad [58]$$

where: $NC_{i,15}$ = the required equipment item quantity rounded to the next larger integer.

NOTE: i ranges in value from m+1 through q.

All other factors are as defined for equation [57].

$$YA_{i,15} = NA_{i,15}X_{i,1,15} \qquad [59]$$

where all factors are as defined for equations [51] and [57], and when k=15 and n=17.

Equation [52] also applies to the cartridge case equipment, when k=15, n=17, m=26, and Q_{15} is as defined for equation [57]. The following equation also applies:

$$YC_{i,15} = NC_{i,15}X_{i,1,15} \qquad [60]$$

where: $YC_{i,15}$= the total cost of equipment item i as previously defined.

NOTE: i ranges in value from m+1 through q.

$NC_{i,15}$ = the value from equation [58].

$X_{i,1,15}$ = the unit equipment cost of equipment item i.

$$Y_{15} = [\sum_{i=1}^{n} YA_{i,15} + \sum_{i=n+1}^{m} YB_{i,15} + \sum_{i=m+1}^{q} YC_{i,15}]1.155+T_{15} \qquad [61]$$

where: Y_{15} = the total cost of all items of equipment required to meet cartridge case production requirements, plus the cost of TME.

$YA_{i,15}$ = the values from equation [59].

$YB_{i,15}$ = the values from equation [52] with subscript k=15.

$YC_{i,15}$ = the values from equation [60].

for k=15; n=17, m=26, and q=30 and are as previously defined.

1.155 = 1.1(1.05), an additional 5 percent allowance for transportation and installation, and 10 percent for layaway costs.

T_{15} = 150.0 for TME.

4. Fuze Line

Based on a discussion with personnel from the Mobilization Engineering Division at Frankford Arsenal, the cost estimates and production rates for the XM714 fuze lines can be used for the full 20mm through 60mm range of ammunition. Therefore, equations [28] and [29] of section IIIB3a(1)(a)6 are to be used here to calculate the total cost of the fuze line(s) required to meet fuze production requirements, including layaway cost and test measuring equipment.

(b) Initial Tooling, over 30mm-60mm

This cost element covers the special initial tooling required for the IPE items shown in Tables III-12 through III-16 for projectiles, LAP, and cartridge cases. No tooling is required for fuzes. The number of initial tooling sets required for each equipment item i in each matrix k is the same as the corresponding equipment item i quantity previously calculated using the equipment quantity equations in section IIIB3a(2)(a)1 through 3. This quantity is expressed for IPE as $N_{i,k}$. Given the previously calculated values of $N_{i,k}$, the resulting initial tooling cost equations are:

1. Projectile (HET, APT, and TPT) and LAP (k=11, 12, 13, and 14, respectively)

$$YA_{i,k} = NA_{i,k}X_{i,j,k} \qquad [62]$$

where: $YA_{i,k}$ = the total cost of the initial tooling required for equipment item i of matrix k.

NOTE: i ranges in value from 1 through n.

$NA_{i,k}$ = the values from equation [49] for the ammunition component specified by the value of k where k=11, 12, 13, or 14, and the appropriate value of i.

$X_{i,j,k}$ = average unit initial tooling cost for equipment item i of matrix k, where the value of subscript j = $NA_{i,k}$ + 2.

$$YB_{i,k} = NB_{i,k}X_{i,j,k} \qquad [63]$$

where: $YB_{i,k}$ = the total cost of the initial tooling required for equipment item i of matrix k.

NOTE: i ranges in value from n+1 through m.

$NB_{i,k}$ = values from equation [50] for the ammunition component specified by the value of k where k = 11, 12, 13, or 14, and for the appropriate value of i.

$X_{i,j,k}$ = as defined in equation [62] where the value of subscript $j = NB_{i,k} + 2$.

$$YC_{i,k} = NC_{i,k}X_{i,j,k} \qquad [64]$$

where: $YC_{i,k}$ = the total cost of the initial tooling required for equipment item i in matrix k. See note following equation [65].

NOTE: i ranges in value from m+1 through q.

$NC_{i,k}$ = values from equation [54] for the ammunition component specified by the value of k = 14 and the appropriate value of i.

$X_{i,j,k}$ = as defined in equation [62] where the value of subscript $j = NC_{i,k} + 2$.

$$Y_k = \sum_{i=1}^{n} YA_{i,k} + \sum_{i=n+1}^{m} YB_{i,k} + \sum_{i=m+1}^{q} YC_{i,k} \qquad [65]$$

where: Y_k = the total cost of all initial tooling necessary to meet production requirements of the ammunition component specified by the value of k.

$YA_{i,k}$ = the value from equation [62].

$YB_{i,k}$ = the value from equation [63].

$YC_{i,k}$ = the value from equation [64].

NOTE 1: n, m, and q assume the following values dependent upon the value of k:

k	n	m	q
11	4	13	-
12	11	14	-
13	4	11	-
14	8	11	15

NOTE 2: the summation of $YC_{i,k}$ only applies to equation [65] when k=14.

2. <u>Cartridge Case - Steel</u> (k=15)

Equations [57], [59], [50], [52], [58], and [60] apply to the initial tooling necessary to meet production requirements for cartridge cases, with subscript k=15, and $Q_{15} = Q_{11} + Q_{12} + Q_{13} = Q_{14}$. The total cost summation equation for cartridge case initial tooling is:

$$Y_k = \sum_{i=1}^{n} YA_{i,k} + \sum_{i=n+1}^{m} YB_{i,k} + \sum_{i=m+1}^{q} YC_{i,k} \qquad [66]$$

where: Y_k = the total cost of all initial tooling necessary to meet production requirements for cartridge cases where k=15 and where all other factors are as defined in equation [61].

for k=15; n=17, m=26, and q=30.

b. Alternative B: 20mm - 40mm

(1) Initial Production Facilities (IPF): IPE and Tooling

As stated in Section IIB1, Alternative B consists of extractions from reference 94. The rationale and methodology of reference 94 are identical to that contained in this study (see Alternative A) and reference 95. The major difference in the Alternative B model is its approach to dimensional adjustments and a moderate difference in mathematical notation.

The approach to the dimensional adjustments to the base model is essentially as follows:

The machine-process listings of the revised model (reference 94) were analyzed in detail to determine which overall component dimensions, if different than those of the base model (reference 95), will impact the production capacities of the individual equipment items. The magnitude of the impacts were then individually assessed and expressed as percentages of change to the basic quantity-of-equipment equations of the reference 95 model. These were translated into modified equations to yield adjusted quantities of equipment required to meet the production rate inputs to the model. Both judgmental assessments were primarily based on review of the detailed manufacturing descriptions of references 96 through 99. Adjustments to alter the number of press drawing, and indirectly the number of associated processes, are based on information obtained by HQ, ARMCOM Plant Operations Directorate.

The mathematical notation used in the cost equations is identical to that used in the base (reference 95) model except for redefinition of the Q values; use of a different symbol for number of shifts; and the addition of a f (fuze) subscript, N_d (number of draws) symbol, component dimension symbols, and symbols denoting constants. The notation applies to the symbolic equations shown in paragraph IIIB3b(2). Solution of the model can be tracked using the sequences of solution shown in Table III-34.

The notation is uniform in applicability to each matrix, and is defined below. Except for S_k, Z, and production-rate (Q) values QE_k, QT_k, and Q_f, which are inputs provided by the estimator, the symbols represent either data base (matrix) values or values yielded by the cost equations.

Subscripts

f Identifies fuze (not a matrix subscript).

i Matrix row; it specifies a specific item of equipment and associated initial tooling.

j Matrix column; it refers either to equipment unit cost, annual equipment capacity per shift, or average unit initial tooling cost.

k The specific matrix; e.g., when k = 1, the HEIT projectile matrix, Table 2, is specified.

Symbols

D Projectile diameter of the ammunition family for which IPF is being estimated. Expressed in mm, this value ranges from 20mm through 40mm.

L_c Cartridge case length, in inches.

L_p Projectile length, in inches.

S_k Number of working shifts assumed in the estimate for the ammunition component identified by the value of k, where a shift is eight hours per day, five days per week (1-8-5). When one shift is assumed, S_k is given the value of 1; similarly, $S_k = 2$ and $S_k = 3$ for two shifts and three shifts, respectively. An additional adjustment to the value of S_k can be made if the estimate is to be based on a working shift other than eight hours per day and/or five days per week. For example, if the desired shift is 2-8-6, $S_k = 2(6/5) = 2.4$. Or, for a 2-10-5 shift, $S_k = 2(10/8) = 2.5$.

S_f Same as S_k, but applicable to fuzes only.

QE_k Peak annual production quantity of the ammunition component specified by the value of k, in millions, for which IPE is required; this value is set equal to zero if no IPE is required.

Q_f — Peak annual fuze production quantity, in millions; this value is set equal to zero if no fuze IPF is required.

QT_k — Peak annual production quantity of the ammunition component specified by the value of k, in millions, for which initial tooling is required; this value is set equal to zero if no initial tooling is required.

$X_{i,j,k}$ — Numerical value (equipment or unit initial tooling cost, or equipment capacity) located at the intersection of row i and column j of matrix k; e.g., $X_{3,2,1}$ provides the value of 1.700 million rounds as the annual capacity per shift for the centerless grinder required to produce the HEIT projectile.

$N_{i,k}$ — Required quantity of the equipment item specified by row i of matrix k. In the solution of the model, this factor represents either the quantity of each equipment item or the number of sets of initial tooling associated with each equipment item. For example, $N_{3,1}$ represents the number of centerless grinders, each grinder having an annual capacity of $S_1X_{3,2,1}$ rounds, required to produce QE_1 or QT_1 HEIT projectiles. This value is rounded to the next larger integer (number of whole equipment items). For example, if the cost equation for $N_{i,k}$ yields a value of 2.005, then $N_{i,k}$ is rounded to 3.

N_d — Number of press drawing operations required in the manufacture of a cartridge case; assumes a value from 3 to 6 depending on case length.

N_f — Number of fuze lines required to meet annual fuze production requirements, rounded to the next larger integer as defined for $N_{i,k}$, above.

$Y_{i,k}$ — Total cost in thousands of dollars of the equipment item specified by row i of matrix k, or its associated initial tooling; it is a function of $N_{i,k}$ and $X_{i,j,k}$.

Y_k — Total cost in thousands of dollars of the equipment needed to meet production requirements of the ammunition component specified by the value of k. It represents the summation of previously-calculated values of $Y_{i,k}$. When applied to IPE, it includes the selective allowances for transportation, installation, layaway, and miscellaneous material handling equipment.

Y_f Total cost of the fuze line(s) required to meet fuze production requirements, including layaway cost.

Z The number of rounds per metal ammunition box known or assumed for the estimate; this input value may or may not be equal to the constant C_3.

T_k Total cost in thousands of dollars of the TME required for the component specified by the value of k; it is independent of the quantity specified by Q_k.

T_f Total cost in thousands of dollars of the TME required for fuzes; it is independent of the quantity specified by Q_f.

Constants

C_1 1.10, a 10 percent allowance for layaway costs. The allowance consists of 6 percent for preservation and 4 percent for crating, handling, and transportation. If the layaway is on site, only the 6 percent factor is applicable; however, the 10 percent factor is used in the model to yield a conservative estimate, on the assumption that on-site layaway versus plant clearance is not known at the time the estimate is being made.

C_2 1.05, a 5 percent allowance for transportation and installation costs.

C_3 100 rounds per ammunition box, the quantity on which the box matrix, Table III-21, is based (see note, bottom of Table III-21).

C_4 1.10, a 10 percent allowance for miscellaneous material handling equipment costs.

C_5 1.2, a constant annual production capacity per fuze line per shift, expressed in millions.

C_6 2, a factor which provides for doubling of the initial tooling matrix value for steel cartridge cases (k=22), when the total case length is greater than 3.5 inches, and the projectile diameter is greater than 20mm and equal to or less than 40mm. This factor is based on the engineering judgment of LCAAP personnel, and is established to account for the higher cost of the heavier press tooling required.

C_7 2,000, the average unit cost per fuze line in thousands of dollars, including transportation and installation cost but excluding layaway cost.

(2) Equation Forms and Sequences of Solution

The cost equations which are solved in the execution of the modified model are listed below in symbolic form. The model contains 50 distinct equations, of which 33 are common to the solution of either a steel-case or aluminum-case family of ammunition. A full solution utilizes 42 equations for a steel-case family, and 41 equations for an aluminum-case family. The initial equations, which solve for the quantity of equipment items required to meet the production-rate input, are identified by equipment item in Tables III-17 through III-24. The sequences of solution following the initial equations are shown by component in Table III-34. In addition, the following should be noted:

(a) Units of measure for inputs are as defined in paragraph IIIB3b(1).

(b) Values of j (matrix column) are specified for all equations in which a value of j is required.

(c) Equations which are iteratively solved over a range of values of i are solved for all values of i within each matrix except as otherwise noted.

(d) Equations for $N_{i,k}$ (equipment item quantity) are identified as 1a, 2a, ..., 14a for IPE, and 1b, 2b, ..., 14b for initial tooling. The equations are identical except for the variable Q.

(e) Alternative (conditional) choices of equation for $Y_{i,k}$ for steel cartridge cases are provided. These are based on a variation in both the number of drawing operations and the press tonnages required for the blanking and drawing operations, depending on the length and diameter of the cartridge case being estimated. The former variation is accounted for by the addition of draw and trim operations in Table III-23; and the latter is accounted for by variations in affected press tonnages, and the addition of both a second column of equipment unit costs (j=3) to Table III-23 and doubling of the average unit tooling cost (equation 29) to accommodate the higher tonnages. These variations are taken directly from the reference 95 model, but with additional draw-trim operations to accommodate a wider range of case lengths. Only variations in drawing, trimming, and associated material-treatment processes driven by case length are included in the aluminum case model, and these are handled by varying the number of equipment items (values of i), not with conditional equations.

Equation Number	Equation
	IPE
1a	$N_{i,k} = \frac{QE_k}{S_k X_{i,j,k}} \left[1+0.4\left(\frac{DL_p}{115} -1\right)\right]$, where j = 2
2a	$N_{i,k} = \frac{QE_k}{S_k X_{i,j,k}} \left[1+0.4\left(\frac{D}{25} -1\right)\right]$, where j = 2
3a	$N_{i,k} = \frac{D\ QE_k}{25\ S_k X_{i,j,k}}$, where j = 2
4a	$N_{i,k} = \frac{QE_k}{S_k X_{i,j,k}} \left[1+0.1\left(\frac{DL_p}{115} -1\right)\right]$, where j = 2
5a	$N_{i,k} = \frac{QE_k}{S_k X_{i,j,k}}$, where j = 2
6a	$N_{i,k} = \frac{C_3\ QE_k}{Z\ S_k X_{i,j,k}}$, where j = 2
7a	$N_{i,k} = \frac{L_p\ QE_k}{4.6\ S_k X_{i,j,k}}$, where j = 2
8a	$N_{i,k} = \frac{QE_k}{S_k X_{i,j,k}} \left[1+0.3\left(\frac{L_c}{5.4} -1\right)\right]$, where j = 2
9a	$N_{i,k} = \frac{QE_k}{S_k X_{i,j,k}} \left[1+0.2\left(\frac{D}{25} -1\right)\right]$, where j = 2

Equation Number	Equation
10a	$N_{i,k} = \frac{DL_cQE_k}{135\ S_kX_{i,j,k}}\left[\frac{4+(N_d-3)}{4}\right]$,
	where $j = 2$, $N_d = 3$ for $L_c \leq 3.5$ in.,
	$N_d = 4$ for 3.5 in.$< L_c \leq 7$ in.,
	$N_d = 5$ for 7 in.$< L_c \leq 14$ in., and
	$N_d = 6$ for $L_c > 14$ in.
11a	$N_{i,k} = \frac{DL_cQE_k}{135\ S_kX_{i,j,k}}$, where $j = 2$
12a	$N_{i,k} = \frac{DL_cQE_k}{204.3\ S_kX_{i,j,k}}$, where $j = 2$
13a	$N_{i,k} = \frac{QE_k}{S_kX_{i,j,k}}\left[1+0.4\left(\frac{D}{30}-1\right)\right]$, where $j = 2$
14a	$N_{i,k} = \frac{D\ QE_k}{30\ S_kX_{i,j,k}}$, where $j = 2$
15	$N_f = \frac{QE_k}{C_5S_f}$
16	$Y_{i,k} = N_{i,k}X_{i,j,k}$, where $j = 1$
17	$Y_{i,k} = N_{i,k}X_{i,j,k}$, where $j = 1$, and $i = 1, 2, \ldots., 25$
18	$Y_{i,k} = N_{i,k}X_{i,j,k}$, where $j = 1$, and $i = 1, 2, \ldots., 27$
19	$Y_{i,k} = N_{i,k}X_{i,j,k}$, where $j = 3$, $i = 1, 2, \ldots., n$,
	$n = 27$ for 3.5 in.$< L_c \leq 7$ in.,
	$n = 29$ for 7 in.$< L_c \leq 14$ in., and
	$n = 31$ for $L_c > 14$ in.

Equation Number	Equation
20	$Y_{i,k}X_{i,j,k}$, where j = 1, i = 1, 2, ..., n, n = 21 for $L_c \leq 3.5$ in., n = 22 for 3.5 in. $< L_c \leq 7$ in., n = 26 for 7 in. $< L_c \leq 14$ in., n = 27 for $L_c > 14$ in.
21	$Y_k = C_1C_2 \quad Y_{i,k}$
22	$Y_k = C_1C_2C_4 \quad Y_{i,k}$
23	$Y_f = C_7N_fC_1$

Initial Tooling

Equation Number	Equation
1b	$N_{i,k} = \dfrac{QT_k}{S_kX_{i,j,k}}\left[1+0.4\left(\dfrac{DL_p}{115}-1\right)\right]$, where j = 2
2b	$N_{i,k} = \dfrac{QT_k}{S_kX_{i,j,k}}\left[1+0.4\left(\dfrac{D}{25}-1\right)\right]$, where j = 2
3b	$N_{i,k} = \dfrac{D\ QT_k}{25\ S_kX_{i,j,k}}$, where j = 2
4b	$N_{i,k} = \dfrac{QT_k}{S_kX_{i,j,k}}\left[1+0.1\left(\dfrac{DL_p}{115}-1\right)\right]$, where j = 2
5b	$N_{i,k} = \dfrac{QT_k}{S_kX_{i,j,k}}$, where j = 2
6b	$N_{i,k} = \dfrac{C_3QT_k}{Z\ S_kX_{i,j,k}}$, where j = 2

Equation Number	Equation
7b	$N_{i,k} = \dfrac{L_p QT_k}{4.6\ S_k X_{i,j,k}}$, where $j = 2$
8b	$N_{i,k} = \dfrac{QT_k}{S_k X_{i,j,k}} \left[1+0.3\left(\dfrac{L_c}{5.4} - 1\right)\right]$, where $j = 2$
9b	$N_{i,k} = \dfrac{QT_k}{S_k X_{i,j,k}} \left[1+0.2\left(\dfrac{D}{25} - 1\right)\right]$, where $j = 2$
10b	$N_{i,k} = \dfrac{DL_c QT_k}{135\ S_k X_{i,j,k}} \left[\dfrac{4+(N_d-3)}{4}\right]$, where $j = 2$, $N_d = 3$ for $L_c \leq 3.5$ in.; $N_d = 4$ for 3.5 in. $< L_c \leq 7$ in.; $N_d = 5$ for 7 in. $< L_c \leq 14$ in.; $N_d = 6$ for $L_c > 14$ in.
11b	$N_{i,k} = \dfrac{DL_c QT_k}{135\ S_k X_{i,j,k}}$, where $j = 2$
12b	$N_{i,k} = \dfrac{DL_c QT_k}{204.3\ S_k X_{i,j,k}}$, where $j = 2$
13b	$N_{i,k} = \dfrac{QT_k}{S_k X_{i,j,k}} \left[1+0.4\left(\dfrac{D}{30} - 1\right)\right]$, where $j = 2$
14b	$N_{i,k} = \dfrac{D\ QT_k}{30\ S_k X_{i,j,k}}$, where $j = 2$
24	$Y_{i,k} = N_{i,k} X_{i,j,k}$, where $j = N_{i,k} + 2$
25	$Y_{i,k} = N_{i,k} X_{i,j,k}$, where $j = N_{i,k} + 3$, $i = 1, 2, \ldots, n$, $n = 25$ for $L_c \leq 3.5$ in.; $n = 27$ for 3.5 in. $< L_c \leq 7$ in.; $n = 29$ for 7 in. $< L_c \leq 14$ in.; $n = 31$ for $L_c > 14$ in.

Equation Number	Equation
26	$Y_{i,k} = N_{i,k}X_{i,j,k}$, where $j = N_{i,k} + 2$, $i = 1, 2, \ldots., n$,
	$n = 21$ for $L_c \leq 3.5$ in.
	$n = 22$ for $3.5 \text{ in.} < L_c \leq 7$ in.
	$n = 26$ for $7 \text{ in.} < L_c \leq 14$ in.
	$n = 27$ for $L_c > 14$ in.
27	$Y_k = \quad Y_{i,k}$
28	$Y_k = \left[(1.02)^{D-25}\right] \sum Y_{i,k}$
29	$Y_k = C_6 \left[(1.02)^{D-25}\right] \sum Y_{i,k}$
30	$T_k = 26.6$, where $k = 16$ and 17
31	$T_k = 25.0$, where $k = 18$
32	$T_k = 29.9$, where $k = 19$
33	$T_k = 11.7$, where $k = 20$
34	$T_k = 42.7$, where $k = 21$
35	$T_k = 60.5$, where $k = 22$ and 23
36	$T_f = 198.2$ for fuzes

4. Tank Main Armament

a. Industrial Plant Equipment (IPE)

The IPE required for the manufacture of an over 60mm through 152mm tank main armament ammunition family is shown in Tables III-25 through III-33. These equipment lists were developed from detailed analysis of the various manufacturing processes (reference 6 is typical) associated to this family of ammunition. Appropriate modifications to these processes were made where specific process elements were known to be obsolete. In addition to the equipment costs and special initial tooling cost per equipment item obtained from Tables III-25 through III-33, the cost model selectively includes allowances in the cost equations for test and measuring equipment, transportation, installation and layaway costs.

Tables III-25 through III-33 constitute matrices from which the cost model selects cost values and equipment capacities required for the solution of the cost equation. The matrices are arranged in a step-wise range of progression with the upper end of each range as the base; e.g., 105mm is the base for the over 90mm - 105mm range and is applicable throughout this range. The notation used in the cost equations applies uniformly to each matrix and is identical to that presented previously (see Section IIIB3a(1)(a)).

Attention is brought to Tables III-25 and III-26 in that they both present a TPT projectile. This is essentially due to convention; that is, the tank ammunition family usually requires a ballistically matched TPT projectile for most of the combat projectiles.

(1) Projectile

HET and TPT (k=24)

$$N_{i,24} = \frac{Q_{24}}{C_{24} X_{i,j,24}} \qquad [67]$$

where: $N_{i,24}$ = the required equipment item quantity rounded to the next larger integer.

Q_{24} = the annual production quantity requirement.

C_{24} = the assumed number of shifts.

$X_{i,j,24}$ = the annual capacity per shift of equipment item i used to produce projectiles, and as restricted by j.

NOTE: For the HET projectile, subscript j assumes the following values.

j=2 for over 60-75mm
j=4 for over 75-90mm
j=6 for over 90-105mm
j=8 for over 105-120mm
j=10 for over 120-152mm

For the TPT projectile, subscript j assumes the following values.

j=3 for over 60-75mm
j=5 for over 75-90mm
j=7 for over 90-105mm
j=9 for over 105-120mm
j=11 for over 120-152mm

$$Y_{i,24} = N_{i,24} X_{i,1,24} \qquad [68]$$

where: $Y_{i,24}$ = the total cost of equipment item i used to produce either the HET or TPT projectile as restricted by j.

$N_{i,24}$ = the value from equation [67].

$X_{i,1,24}$ = the unit cost of equipment item i used to produce projectiles.

$$Y_{24} = \sum Y_{i,24}(1.155) + T_{24} \qquad [69]$$

where: Y_{24} = the total cost of all items of equipment necessary to meet the production requirement of each projectile as restricted by j, plus the cost of TME.

$Y_{i,24}$ = the values from equation [68].

1.155 = 1.1(1.05), an additional 5 percent allowance for transportation and installation, and 10 percent for layaway costs.

T_{24} = 439.0 for TME, and is independent of j.

<u>APT and TPT</u> (k=25)

Equations [67], [68], and [69] apply to the equipment required for the APT and its ballistically matched TPT projectile, with subscript k=25 and the restrictions of subscript j are as follows:

For the APT projectile
j=2 for over 60-75mm
j=4 for over 75-90mm
j=6 for over 90-120mm

and for the TPT projectile

j=3 for over 60-75mm
j=5 for over 75-90mm
j=7 for over 90-120mm

Additionally, T_{25} = 102 for TME and is independent of j.

(2) LAP

Metal Cartridge Cased (k=26)

$$N_{i,26} = \frac{Q_{26}}{C_{26}X_{i,j,26}} \qquad [70]$$

where: $N_{i,26}$ = the required equipment item quantity rounded to the next larger integer.

Q_{26} = the annual production quantity requirement.

C_{26} = the assumed number of shifts.

$X_{i,j,26}$ = the annual capacity per shift of equipment item i required to LAP ammunition components, and as restricted by the subscript j as follows:

j=2 for over 60-75mm
j=3 for over 75-90mm
j=4 for over 90-105mm
j=5 for over 105-120mm
j=6 for over 120-152mm

$$Y_{i,26} = N_{i,26}X_{i,1,26} \qquad [71]$$

where: $Y_{i,26}$ = the total cost of equipment item i required to LAP ammunition components, and as restricted by j.

$N_{i,26}$ = the value from equation [70].

$X_{i,1,26}$ = the unit cost of equipment item i required to LAP ammunition components.

$$Y_{26} = \sum Y_{i,26}(1.2705) + T_{26} \qquad [72]$$

where: Y_{26} = the total cost of all items of equipment required to LAP ammunition components, plus the cost of TME, and as restricted by j.

$Y_{i,26}$ = the values from equation [71].

1.2705 = 1.1(1.155), a 10 percent allowance for miscellaneous material handling equipment applied in addition to the allowances previously defined.

T_{26} = 96.0 for TME.

<u>Combustible Cartridge Cased</u> (k=27)

$$N_{i,27} = \frac{Q_{27}}{C_{27}X_{i,j,27}} \quad [73]$$

where: $N_{i,27}$ = the required equipment item quantity rounded to the next larger integer.

Q_{27} = the annual production quantity requirement.

C_{27} = the assumed number of shifts.

$X_{i,j,27}$ = the annual capacity per shift of equipment item i required to LAP ammunition components, and as restricted by the subscript j as follows:

j=2 for over 60-75mm
j=3 for over 75-90mm
j=4 for over 90-105mm
j=5 for over 105-120mm
j=6 for over 120-152mm

$$Y_{i,27} = N_{i,27}X_{i,1,27} \quad [74]$$

where: $Y_{i,27}$ = the total cost of equipment item i required to LAP ammunition components, and as restricted by j.

$N_{i,27}$ = the value from equation [73].

$X_{i,1,27}$ = the unit cost of equipment item i required to LAP ammunition components.

$$Y_{27} = \sum Y_{i,27}(1.21) + T_{27} \quad [75]$$

where: Y_{27} = the total cost of all items of equipment required to LAP ammunition components, plus the cost of TME, and as restricted by j.

$Y_{i,27}$ = the values from equation [74].

1.21 = 1.1(1.1), an additional 10 percent allowance for miscellaneous material handling equipment, and 10 percent for layaway costs (see NOTE on Table III-28).

T_{27} = the costs for TME are included in the equipment costs (see NOTE on Table III-28).

(3) Cartridge Case

Steel (k=28)

$$N_{i,28} = \frac{Q_{28}}{C_{28}X_{i,j,28}} \qquad [76]$$

where: $N_{i,28}$ = the required equipment item quantity rounded to the next larger integer.

Q_{28} = the annual production quantity requirement.

C_{28} = the assumed number of shifts.

$X_{i,j,28}$ = the annual capacity per shift of equipment item i used to produce cartridge cases, and as restricted by the subscript j as follows:

j=2 for over 60-75mm
j=3 for over 75-90mm
j=4 for over 90-105mm
j=5 for over 105-120mm

$$Y_{i,28} = N_{i,28}X_{i,1,28} \qquad [77]$$

where: $Y_{i,28}$ = the total cost of equipment item i used to produce cartridge cases, and as restricted by j.

$N_{i,28}$ = the value from equation [76].

$X_{i,1,28}$ = the unit cost of equipment item i used to produce cartridge cases.

$$Y_{28} = \sum Y_{i,28}(1.155) + T_{28} \qquad [78]$$

where: Y_{28} = the total cost of all items of equipment necessary to meet the production requirement for cartridge cases as restricted by j, plus the cost of TME.

$Y_{i,28}$ = the values from equation [77].

1.155 = 1.1(1.05), an additional 5 percent allowance for transportation and installation, and 10 percent for layaway costs.

T_{28} = 163.0 for TME.

Spiral Wrap, Steel (k=29)

Equations [76], [77], and [78] apply to the spiral wrap, steel cartridge case equipment, with subscript k=29 and the restrictions of subscript j as follows:

j=2 for over 60-90mm
j=3 for over 90-120mm

Additionally, T_{29} = 73.6 for TME.

Brass (k=30)

Equations [76], [77], and [78] apply to the brass cartridge case equipment, with subscript k=30 and the restrictions of subscript j as follows:

j=2 for over 60-75mm
j=3 for over 75-90mm
j=4 for over 90-105mm
j=5 for over 105-120mm

Additionally, T_{30} = 145.0 for TME.

Combustible (k=31)

Equations [76], [77], and [78] apply to the combustible cartridge case equipment, with k=31 and the restrictions of subscript j as follows:

j=2 for over 60-76mm
j=3 for over 76-90mm
j=4 for over 90-105mm
j=5 for over 105-120mm
j=6 for over 120-152mm

Additionally, T_{31} = 20.4 at j=2
T_{31} = 20.6 at j=3
T_{31} = 20.7 at j=4
T_{31} = 21.6 at j=5
T_{31} = 20.0 at j=6

NOTE: The contents of Table III-32, Combustible Cartridge Case, were estimated under the major groundrule that the combustible cartridge cased ammunition would possess the same operational or performance characteristics as the current conventional tank main armament ammunition of the following calibers: 60mm, 76mm, 90mm, 105mm, 120mm, and 152mm.

(4) Fuze (k=32)

$$N_{i,32} = \frac{Q_{32}}{C_{32}X_{i,2,32}} \qquad [79]$$

where: $N_{i,32}$ = the required equipment item quantity rounded to the next larger integer.

Q_{32} = the annual production quantity requirement.

C_{32} = the assumed number of shifts.

$X_{i,2,32}$ = the annual capacity per shift of equipment item i used to produce fuzes.

$$Y_{i,32} = N_{i,32}X_{i,1,32} \qquad [80]$$

where: $Y_{i,32}$ = the total cost of equipment item i used to produce fuzes.

$N_{i,32}$ = the value from equation [79].

$X_{i,1,32}$ = the unit cost of equipment item i used to produce fuzes.

$$Y_{32} = \sum Y_{i,32}(1.155) + T_{32} \qquad [81]$$

where: Y_{32} = the total cost of all items of equipment necessary to meet the production requirement for fuzes, plus the cost of TME.

$Y_{i,32}$ = the values from equation [80].

1.155 = 1.1(1.05), an additional 5 percent allowance for transportation and installation, and 10 percent for layaway costs.

T_{32} = 17.8 for TME.

b. Initial Tooling

This cost element covers the special initial tooling required for the IPE items shown in Tables III-25 through III-33 for projectiles, LAP, cartridge cases, and fuzes. The number of initial tooling sets required for each equipment item i in each matrix k and as restricted by j, is the same as the corresponding equipment item i quantity ($N_{i,k}$) previously calculated for IPE using the equipment quantity equations in section IIIB4a. Given the previously calculated values of $N_{i,k}$, the resulting initial tooling costs for each ammunition component are estimated from the following general equations:

$$Y_{i,k} = N_{i,k}X_{i,j,k} \qquad [82]$$

where: $Y_{i,k}$ = the total cost of the initial tooling required for equipment item i of matrix k and as restricted by j.

$N_{i,k}$ = the value from the equation number identified below, as applicable for the value of k for the component being estimated.

$X_{i,j,k}$ = the average unit tooling cost for equipment item i of matrix k, where the value of subscript j is defined below.

$$Y_k = \sum Y_{i,k} \qquad [83]$$

where: Y_k = the total cost of all initial tooling required to meet production requirements of the ammunition component specified by the value of k.

$Y_{i,k}$ = the values from equation [82].

The following information related to $N_{i,k}$ and subscripts j and k is to be applied to equations [82] and [83].

(1) Projectile

HET and TPT (k=24)

The values of $N_{i,k}$ are taken from equation [67]. In equation [82], subjscript $j=N_{i,k} + 11$.

APT and TPT (k=25)

The values of $N_{i,k}$ are taken from equation [67] as restricted by j where k=25. In equation [82], subscript $j = N_{i,k} + 7$.

(2) LAP

Metal Cartridge Cased (k=26)

The values of $N_{i,k}$ are taken from equation [70]. In equation [82], subscript $j = N_{i,k} + 6$.

Combustible Cartridge Cased (k=27)

The tooling is included in the equipment cost (see NOTE on Table III-28).

(3) Cartridge Case

Steel (k=28)

The values of $N_{i,k}$ are taken from equation [76]. In equation [82], subscript $j = N_{i,k} + 5$.

Spiral Wrap, Steel (k=29)

The values of $N_{i,k}$ are taken from equation [76] as restricted by j where k=29. In equation [82], subscript $j = N_{i,k} +3$.

Brass (k=30)

The values of $N_{i,k}$ are taken from equation [76] as restricted by j where k=30. In equation [82], subscript $j = N_{i,k} + 5$, except as follows:

Where i=1 on Table III-31, no equipment is required since the cartridge case blank is purchased. Therefore, it is recommended that the estimator coordinate the requirement for Government furnished tooling with the apppropriate ammunition production base personnel.

Combustible (k=31)

The values of $N_{i,k}$ are taken from equation [76] as restricted by j where k=31. In equation [82], the values of subscript j are as follows:

j=7 for 60mm
j=8 for over 60-76mm
j=9 for over 76-90mm
j=10 for over 90-105mm
j=11 for over 105-120mm
j=12 for over 120-152mm

(4) Fuze (k=32)

The values of $N_{i,k}$ are taken from equation [79]. In equation [82], subscript j=3.

TABLE 111-2 HEIT PROJECTILE (k=1)(FY74$)

Matrix Values $X_{i,j,k}$

i	Equipment Item	Equipment Unit Cost In Thousands (j=1)	Equipment Capacity/Shift In Millions (j=2)	Avg Unit Tooling Cost ($ in thousands) as $N_{i,k}$ = 1,2,3,...., ∞ (j=3)	(j=4)	(j=5)	(j=6)	(j=7)	(j=8)	(j=9)	(j=10)	(j=11)	(j=12)	(j=13)	(j=14 → ∞)
1	Auto Screw Machine	$78.460	.383	4.40	4.400	4.400	4.400	4.400	2.934	2.934	2.934	2.444	2.444	2.444	2.384 →
2	Secondary Open Chucker	66.010	1.133	2.20	1.650	1.466	1.466	1.320							→
3	Centerless Grinders	36.120	1.700	0											→
4	35-Ton Hydraulic Press	14.945	1.700	2.20	1.650										→
5	4-Ton Hydraulic Press	7.470	1.700	0.60	0.440	0.440	0.385								→
6	Press, Band Swaging	6.230	2.300	4.40	3.300										→
7	Phosphate Coating Unit	57.290	2.300	0											→
8	Magnetic Inspect Mach	33.630	2.300	0											→
9	Wash, Rinse & Dry Unit	22.420	2.300	0											→
10	Marking Machine	3.110	2.300	0											→
11	Painting Machine	43.590	4.600	0											→

TABLE 111-3 APT PROJECTILE (k=2)(FY74$)

Matrix Values $X_{i,j,k}$

i	Equipment Item	Equipment Unit Cost In Thousands (j=1)	Equipment Capacity/Shift In Millions (j=2)	Avg Unit Tooling Cost ($ in thousands) as $N_{i,k}$=1,2,3,...., ∞ (j=3)	(j=4)	(j=5)	(j=6)	(j=7)	(j=8)	(j=9 --- ∞)
1	Auto Screw Machine	$78.406	.413	7.70	7.700	4.767	4.400	4.400	4.034	→
2	Single Spindle Screw Mach	22.420	.825	4.40	3.300	2.934				→
3	Centerless Grinders	36.120	2.250	0						→
4	Tocco Indus Heat Unit	43.590	2.250	0						→
5	Turret Lathe	28.645	1.125	1.10	.825					→
6	Press, 15 Ton	7.470	1.125	2.20	1.650					→
7	Degreaser	22.420	2.250	0						→
8	Magnetic Part Insp Machine	33.630	2.250	0						→
9	Phosphate Coating Unit	70.990	2.250	0						→
10	Painting Machine	43.590	2.250	0						→

TABLE III-4 TPT PROJECTILE (k=3)(FY 74$)

		Matrix Values $X_{i,j,k}$								
		Equipment Unit Cost In Thousands	Equipment Capacity/Shift In Millions	Avg Unit Tooling Cost ($ in thousands) as $N_{i,k}$=1,2,3,...,∞						
i	Equipment Item	(j=1)	(j=2)	(j=3)	(j=4)	(j=5)	(j=6)	(j=7)	(j=8)	(j=9→)
1	Auto Screw Machine	$78.460	.542	4.40	3.300	3.300	3.300	3.300	2.567	→
2	Auto Screw Machine	66.040	.650	3.96	2.420	2.420	2.420	1.496	→	→
3	Centerless Grinders	36.120	1.625	0	→	→	→	→	→	→
4	Hydraulic Press (35 Ton)	14.945	1.625	2.20	1.650	→	→	→	→	→
5	Press, Band Swaging	6.230	1.625	4.40	3.300	→	→	→	→	→
6	Phosphate Coating Unit	70.990	1.625	0	→	→	→	→	→	→
7	Magnetic Part Insp Machine	33.630	3.250	0	→	→	→	→	→	→
8	Wash, Rinse & Dry Unit	22.420	3.250	0	→	→	→	→	→	→
9	Marking Machine	3.110	3.250	0	→	→	→	→	→	→
10	Painting Machine	28.645	3.250	0	→	→	→	→	→	→

TABLE III-5 DISCARDING SABOT-LESS PENETRATOR (k=4)(FY75$)

	EQUIPMENT ITEM			MATRIX VALUES $X_{i,j,k}$				
			Equipment Unit Cost In Thousands	EQUIPMENT CAPACITY/SHIFT IN MILLIONS				Avg Unit Tooling Cost ($ In Thousands) as $N_{i,k}$= 1,2,3,..., ∞
i	Component/Operation	Machine	j=1	20mm j=2	Over 20-25mm j=3	Over 25-30mm j=4	Over 30-35mm j=5	j=6→∞
1	Windshield	8 Spindle Screw Mach	95.0	.936	.749	.624	.541	11.8
2	Windshield	Anodize Unit	100.0	5.200	4.160	3.474	2.964	5.0
3	Base	Screw Mach	57.7	.624	.499	.416	.354	5.0
4	Base	Screw Mach	57.7	1.024	.884	.738	.624	5.0
5	Base	Lathe	55.0	.624	.499	.416	.354	3.0
6	Base	Slotting Mach	50.0	.468	.374	.312	.270	2.0
7	Base	Anodize Unit	100.0	5.200	4.160	3.474	2.964	5.0
8	Sabot	Molding Equip	20.0	.998	.801	.666	.572	10.0
9	Sabot	Screw Mach	57.7	.499	.499	.499	.499	5.0
10	Penetrator/Windshield Assy	Press	40.0	.749	.749	.749	.749	5.0
11	Base Assy.	Press	40.0	.749	.749	.749	.749	3.0
12	Sabot Assy.	Press	40.0	.749	.749	.749	.749	3.0
13	Sabot Assy.	Screw Mach	57.7	.499	.499	.499	.499	5.0
14	Tracer Extension	8 Spindle Screw Mach	95.0	1.498	1.196	.998	.853	5.0
15	Tracer Ext. Assy.	Inserting Press	20.0	1.498	1.498	1.498	1.498	3.0

TABLE 111-6 TUNGSTON ALLOY PENETRATOR (k=5)(FY75$)

	EQUIPMENT ITEM		Equipment Unit Cost In Thousands	MATRIX VALUES $X_{i,j,k}$							
				EQUIPMENT CAPACITY/SHIFT IN MILLIONS				Avg Unit Tooling Cost ($ In Thousands) as $N_{i,k} = 1,2,3,\ldots\varphi$		TME Cost ($ In Thous) As $N_{i,k} = 1,2,3,\ldots\varphi$	
				20mm	Over 20-25mm	Over 25-30mm	Over 30-35mm				
i	Operation	Machine	j=1	j=2	j=3	j=4	j=5	j=6	j=7	j=8	j=9
1	Mill Powder Mix	20 Gal Ball Mill	13.5	.395	.204	.119	.075	0	0	0	0
2	Lubricate Mix	Blender	4.0	.795	.408	.235	.148	0	0	0	0
3	Die Compact	20T Press Hyd	36.0	1.907	.978	.566	.356	1.2	3.2	1.3	1.7
4	Pre-Sinter	Tube Furnace	14.7	.110	.056	.033	.021	0	0	0	0
5	Sinter	Dbl Zone Furnace	24.4	.125	.065	.037	.024	0	0	0	0
6	Post Sinter	Dbl Tube Furnace	17.0	.358	.183	.106	.067	0	0	0	0
7	Machine Contour	Auto Screw Mach	100.2	.385	.312	.260	.223	1.2	10.4	1.4	3.4
8	Mach Tracer Hole	Auto Screw Mach	100.2	.800	.645	.541	.458	1.1	11.5	1.3	1.6

TABLE 111-7 LINK (k=6)(FY74$)

		Matrix Values $X_{i,j,k}$						
		Equipment Unit Cost In Thousands	Equipment Capacity/Shift In Millions	Avg Unit Tooling Cost ($ in thousands) as $N_{i,k}=1,2,3,\ldots,\infty$				
i	Equipment Item	(j=1)	(j=2)	(j=3)	(j=4)	(j=5)	(j=6)	(j=7 ⟶ ∞)
1	150-Ton Blank & Form Press	$114.580	4.025	121.00	96.260	84.342	→	→
2	435 Mult. Slide Press	85.935	4.025	44.00	35.754	33.003	→	→
3	Secondary Opr. OBI Press	28.645	2.683	16.50	16.502	12.835	12.376	→
4	Heat Treat Furnance	149.450	8.050	0	→	→	→	→
5	Vibratory Deburring Machines	70.000	4.025	0	→	→	→	→
6	Assembly Machine	21.170	4.025	0	→	→	→	→
7	Panschoff Wash & Dry	28.645	4.025	0	→	→	→	→
8	Vapor Degreaser	14.945	4.025	0	→	→	→	→
9	Phosphate Coating Sys.	85.935	8.050	0	→	→	→	→

TABLE 111-8 BOX (k=7) (FY74$)

Matrix Values $X_{i,j,k}$

i	Equipment Item	Equipment Unit Cost In Thousands (j=1)	Equipment Capacity/Shift In Millions (j=2)	Avg Unit Tooling Cost ($ in Thousands) as $N_{i,k}$=1,2,3,...,∞ (j=3)	(j=4)	(j=5)	(j=6)	(j=7)	(j=8)	(j=9)	(j=10 → ∞)
1	Punch Press 135-150 Ton	$28.645	6.7	60.50	60.500	60.500	52.255	51.705	51.339 →		
2	Punch Press 60-70 Ton	14.945	6.2	8.80	8.800	8.800	8.388	8.361	8.342	8.329 →	
3	Punch Press 20-30 Ton	7.470	8.3	4.40	4.400	4.034	3.988	3.960 →			
4	Punch Brake 50-60 Ton	14.945	8.3	8.80	8.800	8.435	8.388	8.361 →			
5	Seam Welders	17.440	5.0	0 →							
6	Spot Welders	11.210	2.8	0 →							

NOTE: $X_{i,2,k}$ (the production equipment capacity for ammunition boxes) is expressed in rounds of ammunition instead of boxes, i.e 67,000 boxes times 100 rounds per box = 6,700,000 rounds

TABLE 111-9 LAP (k=8) (FY74$)

Matrix Values $X_{i,j,k}$

i	Equipment Item	Equipment Unit Cost In Thousands (j=1)	Equipment Capacity/Shift In Millions (j=2)	Avg Unit Tooling Cost ($ in Thousands) as N_{ik}=1,2,3,...,∞ (j=3)	(j=4)	(j=5)	(j=6)	(j=7)	(j=8)	(j=9)	(j=10)	(j=11)	(j=12)	(j=13 →)
1	Blending Units	$ 9.960	4.200	0 →										
2	Pelletizers	21.170	4.200	5.50	4.400 →									
3	Charging Machine	191.800	1.680	16.50	16.500	16.500	16.500	16.500 →						
4	Straight Line Loaders	78.460	1.680	8.80	8.800	8.800	8.800	4.400 →						
5	Auto Fuze Assemblers	43.590	.764	1.10	1.100	1.100	1.100	1.100	1.100	1.100	1.100	1.100	1.100	3.00 →
6	Gage & Weight	78.460	4.200	13.20	11.000 →									
7	Can Sealer	9.960	2.800	0 →										
8	Marking Machine	14.945	4.200	0 →										

TABLE III-10 STEEL CARTRIDGE CASE (k=9)(FY74$)

Matrix Values $X_{i,j,k}$

i	Operation	Machine	Equipment Unit Cost In Thousands (j=1)	Equipment Unit Cost In Thousands (j=2)	Equipment Capacity/Shift In Millions (j=3)	Avg Unit Tooling Cost ($ in Thousands) as $N_{i,k}=1,2,3,\ldots\infty$ (j=4)	(j=5)	(j=6)	(j=7)	(j=8)	(j=9)	(j=10)	(j=11)	(j=12 → ∞)
1	Blank	100T(j=1)/200T(j=2)	$ 62.270	124.540	5.050	11.00	6.821							→
2	Wash/Dry	42" Spiral 4 Stage	31.140	31.140	5.050	0								→
3	Anneal	9K #/hr. 1400°	467.000	467.000	10.100	0								→
4	Descal & Coat	60" Spiral 9 Stage	137.000	137.000	10.100	0								→
5	Coin Cup	400T	249.090	249.090	3.367	2.64	2.090	1.906						→
6	1st Draw	150T(j=1)/200T(j=2)	93.410	124.540	3.367	0.88	.715	.660						→
7	2d Draw	100T(j=1)/200T(j=2)	62.270	124.540	3.367	0.88	.715	.660						→
8	2d Draw Trim	Rotary	19.930	19.930	2.020	0.55	.550	.404	.385	.374				→
9	3d Draw	100T(j=1)/200T(j=2)	62.270	124.540	3.367	0.88	.715	.660						→
10	3d Draw Trim	Rotary	21.170	21.170	2.020	0.55	.550	.404	.385	.374				→
11	Indent & Head	200T	124.540	124.540	2.020	0.99	.990	.440	.413	.396				→
12	Head Turn	Screw Mach 8 Spdle	92.160	92.160	1.263	5.50	5.500	5.500	5.500	2.860	2.750	2.750	2.613	→
13	Pierce Flash Hole	5T Horizontal	57.290	57.290	3.367	0.55	.440	.404						→
14	Pretaper Trim	Rotary	21.170	21.170	2.525	0.55	.550	.404	.385					→
15	Taper	65T Horizontal	74.730	74.730	3.367	1.65	1.155	.990						→
16	Preharden Wash	42" 4 Stage	32.380	32.380	10.100	0								→
17	Harden & Quench	1800° Tube Type	249.090	249.090	5.050	0								→
18	Temper	800° Belt	70.990	70.990	5.050	0								→
19	Base Anneal	50 KW Ind	186.820	186.820	5.050	0								→
20	Mouth Anneal	50 KW Ind	118.320	118.320	5.050	0								→
21	Final Trim	Multiple Shimmy Trim	54.800	54.800	3.367	0.55	.440	.404						→
22	Rinse & Dry	42" 2 Stage	26.150	26.150	10.100	0								→
23	Mouth Size	20T	13.700	13.700	3.367	2.20	1.650	1.466						→
24	Coating System	Lacquer, Varnish, or Phosph	286.450	286.450	5.050	0								→
25	4th Draw	150T(j=1/200T(j=2)	93.410	124.540	3.367	0.88	.715	.660						→
26	4th Draw Trim	Rotary	21.170	21.170	2.020	0.55	.550	.404	.385	.396				→

TABLE III-11 ALUMINUM CARTRIDGE CASE (k=10)(FY74$)

Equipment Item			Matrix Values $X_{i,j,k}$					
			Equipment Unit Cost In Thousands	Equipment Capacity/Shift In Millions	Avg Unit Tooling Cost ($ in Thousands) as $N_{i,k}=1,2,3,\ldots,\infty$			
i	Operation	Machine	(j=1)	(j=2)	(j=3)	(j=4)	(j=5)	(j=6 → ∞)
1	Blank & Cup	250 T Press Mech	204	8.67	9.91 →			→
2	Anneal	Annealing Oven	161	10.33	0 →			→
3	Clean, Lub & Dry	Clean & Lub Equip	174	10.33	0 →			→
4	1st Draw	75 T Press Mech	120	8.67	.79 →			→
5	2d Draw	75 T Press Mech	106	8.67	.79 →			→
6	Trim	V&O Trimmer	241	8.67	.50 →			→
7	3d Draw	75 T Press Mech	106	8.67	.79 →			→
8	4th Draw	75 T Press Mech	106	8.67	.79 →			→
9	Trim	V&O Trimmer	224	8.67	.50 →			→
10	Wash, Lub & Dry	2-Stage Wash, Lub & Dry Equip	167	11.08	0 →			→
11	Pocket & Head	175 T Heading Press	568	8.67	1.71 →			→
12	Taper	75 T Press	213	8.67	2.97 →			→
13	Heat Treat	Elec Oven & Quench Tank	66	20.83	0 →			→
14	Age	Aging Oven	63	20.83	0 →			→
15	Machine Head	8 Spindle Screw Mach	82	2.17	4.95	4.95	4.16	3.74 →
16	Final Trim	Mul. Shimmy Trim	49	2.92	.50	.40	.36 →	→
17	Mouth Anneal	Induction Annealer	106	10.33	0 →			→
18	Anodize	Auto-Anodize	134	1.08	0 →			→
19	Identify	Marking Mach	4	8.67	0 →			→

TABLE 111-12 HET PROJECTILE (k=11)(FY74$)

Matrix Values $X_{i,j,k}$

i	Operation	Machine	Equipment Unit Cost In Thousands (j=1)	Equipment Capacity/Shift In Millions (j=2)	Avg Unit Tooling Cost ($ in Thousands) as $N_{i,k}$=1,2,3,..., ∞ (j=3)	(j=4)	(j=5)	(j=6)	(j=7)	(j=8 → ∞)
1	Form & Drill	6 Spindle Bar Machine	$106.6	.118	8.000	8.000	8.000	3.000		→
2	Broach Bank	2DT Press Hyd	89.9	.422	28.200	20.350	17.750			→
3	Bonderize	Tanks	35.0	.591	12.000					→
4	Paint	Paint Machine	50.0	.348	0					→
5	Tracer Hole	B & S Lathe	36.4	.156	1.000	1.000	1.000	.400		→
6	Cold Nose	75T Press Hyd	106.3	.422	6.000	4.375	3.825			→
7	Size	Grinder	36.4	.161	5.600					→
8	Bore & Chamfer	4 Spindle Chucker	117.4	.231	9.600	9.600	9.600	4.275		→
9	Tap for Fuze	Tapping Machine	17.3	.127	.600					→
10	Mark	Stamping Machine	7.4	1.267	2.000	1.475	1.285			→
11	Blank Cover	#2 1/2 OBI Press	4.2	1.267	1.400	1.000	.850			→
12	Weld Cover	50KVA Welder	3.5	.338	.600					→
13	Remove Teat	5T Bench Press	2.0	1.200	.450	.300				→

TABLE 111-13 APT PROJECTILE (k=12)(FY74$)

Matrix Values $X_{i,j,k}$

i	Operation	Machine	Equipment Unit Cost In Thousands (j=1)	Equipment Capacity/Shift In Millions (j=2)	Avg Unit Tooling Cost ($ in Thousands) as $N_{i,k}$= 1,2,3,... ∞ (j=3)	(j=4)	(j=5)	(j=6 → ∞)
1	Form & Cutoff	Bar Machine	$106.6	.077	4.500	4.500	2.500	→
2	Broach	60T Press Hyd	106.3	.422	6.000	4.375	3.825	→
3	Clean	Auto Wash Conveyor	8.0	.130	0			→
4	Heat Treat	100KW Tocco Induction	105.6	.192	3.600			→
5	Bonderize	Tanks	35.0	.591	1.800			→
6	Blank	50T Press	59.0	1.267	2.000	1.800	1.600	→
7	Cup & Draw	60T Press Hyd	95.0	.653	4.800	4.350	4.150	→
8	Trim	20T OBI Press	3.2	.653	1.800	1.600	1.400	→
9	Wash	Tanks	15.0	.653	1.800			→
10	Paint	Paint Equipment	100.0	.348	3.600			→
11	Assemble	Press & Cinch Machine	7.9	1.024	3.400			→
12	Tracer Hole	Turret Lathe	36.4	.156	3.000			→
13	Mark	20T OBI Press	3.2	.653	1.300	.900	.750	→
14	Size	Grinder	36.4	.148	3.600			→

TABLE 111-14 TPT PROJECTILE (k=13)(FY74$)

			Matrix Values $X_{i,j,k}$						
	Equipment Item		Equipment Unit Cost In Thousands	Equipment Capacity/Shift In Millions	Avg Unit Tooling Cost ($ in Thousands) as $N_{i,k}$ = 1,2,3,... ∞				
i	Operation	Machine	(j=1)	(j=2)	(j=3)	(j=4)	(j=5)	(j=6)	(j=7 → ∞)
1	Form & Drill	6 Spindle Bar Machine	$106.6	.118	8.000	8.000	8.000	3.000	
2	Broach Band	2DT Press Hyd	89.9	.422	28.200	20.350	17.750		
3	Bonderize	Tanks	35.0	.591	12.000				
4	Paint	Paint Machine	50.0	.348	0				
5	Remove Teat	5T Bench Press	2.0	1.200	.450	.300			
6	Cold Nose	75T Press Hyd	106.3	.422	6.000	4.375	3.825		
7	Size	Grinder	36.4	.161	5.600				
8	Bore & Chamfer	4 Spindle Chucker	117.4	.231	9.600	9.600	9.600	4.275	
9	Tap for Fuze	Tapping Machine	17.3	.127	.600				
10	Mark	Stamping Machine	7.4	1.267	2.000	1.475	1.285		
11	Tracer Hole	B & S Lathe	36.4	.156	1.000	1.000	1.000	.400	

TABLE 111-15 LAP (k=14)(FY74$)

			Matrix $X_{i,j,k}$					
	Equipment Item		Equipment Unit Cost In Thousands	Equipment Capacity/Shift In Millions	Avg Unit Tooling Cost ($ in Thousands) as $N_{i,k}$ = 1,2,3,...,∞			
i	Operation	Machine	(j=1)	(j=2)	(j=3)	(j=4)	(j=5)	(j=6 → ∞)
1	Assem Adapters & Consolidate	Hyd Press & Truntable	$22.8	1.536	30.500	30.500	22.200	
2	Tracer Assem	Tracer Loader	26.4	.512	1.200			
3	Mix & Heat	Mix, Screen & Melt Equip	20.3	3.072	0			
4	Assem Adapters & Fill	TNT Kettle	24.8	1.536	180.000	180.000	130.000	
5	Probe	Auto Hot Probe Furnace	6.0	.834	3.600			
6	Assem & Clinch Primer	Primer Press	13.2	.512	1.200			
7	Fill Case	Conveyor & Auto Weigh	31.8	1.536	0			
8	Assem & Crimp Projectile	Crimp Case & Proj Equip	7.9	1.024	3.400			
9	Mark Projectile	Stamping Machine	17.4	1.536	2.000			
10	Seat Fuze	Fuze Seating Machine	13.2	.676	3.000			
11	Pellet Assem	Pellet Machine	30.9	1.536	2.000			
12	Gage & Weigh	Shadow Graph	4.0	.768	0			
13	Face Cavity	Air Drills	10.6	.834	3.600			
14	Weigh	Exacto Scale	2.0	.768	0			
15	Mark, Seal & Number	Case Mark	13.7	1.536	0			

TABLE III-16 STEEL CARTRIDGE CASE (k=15)(FY74$)

Matrix Values $X_{i,j,k}$

	Equipment Item		Equipment Unit Cost In Thousands	Equipment Capacity/Shift In Millions	Avg Unit Tooling Cost ($ in thousands) as $N_{i,k}$=1,2,3,...,∞				
i	Operation	Machine	(j=1)	(j=2)	(j=3)	(j=4)	(j=5)	(j=6)	(j=7→∞)
1	Blank	200T Press	$103.2	.768	6.800	4.925	4.275		
2	Flatten & Shave	200T Press	103.2	.768	3.800	2.750	2.400		
3	Wash & Soapcoat	Auto Conveyor	8.0	.653	0				
4	Precup & Cup	350T Press Hyd	105.6	.653	20.000	14.500	12.600		
5	Anneal & Cool	Surface Furnance 1x4	50.0	.653	0				
6	Pickle & Soapcoat	Spec Conveyor 1x4	151.0	.653	0				
7	1st & 2d Draw	350T Press Hyd	105.6	.653	20.000	14.500	12.600		
8	3d Draw	75T Press Hyd	95.0	.653	18.000	13.000	11.300		
9	4th Draw	75T Press Hyd	95.0	.653	18.000	13.000	11.300		
10	Pierce Primer	22T Horn Press	6.4	.653	3.200	2.300	2.000		
11	Mouth Harden	75KW Tocco Induction	190.5	.768	3.600				
12	Stress Relieve	Surface Comb. Furn.	50.0	2.611	0				
13	Pickle, Wash & Dry	Spec Conveyor	151.0	2.611	0				
14	Mouth Reduce & Size	75T Press	35.0	.653	6.400	4.850	4.200		
15	Plate Znphos	Plating Machine	320.0	1.728	13.000				
16	Paint & Bake	Paint, Conveyor & Oven	50.0	1.128	6.000				
17	Stamp	20T Horn Press	6.4	.653	1.300				
18	Rough & Finish Trim	10T Horn Press	12.8	.653	3.600	2.600	2.250		
19	Ream Trim	Power Reamer	4.0	.653	1.500	1.500	1.500	.500	
20	Rotary Trim	V & O Trimmer	24.0	.653	1.200	.900	.800		
21	Head	800T Knuckle Press	232.0	.653	20.000	14.500	12.600		
22	Rough Machine Head	4 Spindle Chucker	117.5	.649	6.000	6.000	6.000	2.000	
23	Form Shoulder	Leonard Tube Master	6.0	.326	2.400	2.400	2.400	.800	
24	Finish Head	4 Spindle Chucker	117.5	.440	6.800	6.800	6.800	2.400	
25	Ream Primer Hole	Drill Press	15.0	.653	1.800	1.300	1.100		
26	Trim & Chanfer	Drill Press	15.0	.653	1.800	1.800	1.800	.600	
27	Mark	20T OBI Press	3.2	.653	1.300	.900	.775		
28	Wash & Dry	Auto Conveyor	8.0	.130	0				
29	Wash & Dry	Spray Wash & Dry	86.0	.653	5.000				
30	Test Hardness-100%	Magnetic Tested	10.0	.768	0				

TABLE III-17 HEIT PROJECTILE (k=16) (FY 75 $)

Matrix Values $X_{i,j,k}$

$N_{i,k}$ Equ	i	Equipment Item	Equipment Unit Cost In Thousands (j=1)	Equipment Capacity/Shift In Millions (j=2)	Avg Unit Tooling Cost ($ in thousands) as $N_{i,k}$=1,2,3,....,∞ (j=3)	(j=4)	(j=5)	(j=6)	(j=7)	(j=8)	(j=9)	(j=10)	(j=11)	(j=12)	(j=13)	(j=14)	(j=15→∞)
1	1	Auto Screw Machine	$87.570	.383	4.88	4.880	4.880	4.880	4.880	3.256	3.256	3.256	2.713	2.713	2.713	2.646	→
2	2	Secondary Open Chucker	73.670	1.133	2.44	1.832	1.628	1.628	1.465	→							
3	3	Centerless Grinders	40.310	1.700	0	→											
4	4	35-Ton Hydraulic Press	16.680	1.700	2.44	1.832	→										
4	5	4-Ton Hydraulic Press	8.340	1.700	0.61	0.488	0.488	0.427	→								
4	6	Press, Band Swaging	6.050	2.300	4.88	3.663	→										
3	7	Phosphate Coating Unit	63.940	2.300	0	→											
3	8	Magnetic Inspect Mach	37.530	2.300	0	→											
3	9	Wash, Rinse & Dry Unit	25.020	2.300	0	→											
2	10	Marking Machine	3.475	2.300	0	→											
3	11	Painting Machine	48.650	4.600	0	→											

TABLE III-18 APT PROJECTILE (k=17) (FY 75 $)

Matrix Values $X_{i,j,k}$

$N_{i,k}$ Equ	i	Equipment Item	Equipment Unit Cost In Thousands (j=1)	Equipment Capacity/Shift In Millions (j=2)	Avg Unit Tooling Cost ($ in thousands) as $N_{i,k}$=1,2,3,....,∞ (j=3)	(j=4)	(j=5)	(j=6)	(j=7)	(j=8)	(j=9→∞)
1	1	Auto Screw Machine	$87.570	.413	8.55	8.550	5.291	4.880	4.880	4.477	→
2	2	Single Spindle Screw Machine	25.020	.825	4.88	3.663	3.256	→			
3	3	Centerless Grinders	40.310	2.250	0	→					
4	4	Tocco Indus Heat Unit	48.650	2.250	0	→					
2	5	Turret Lathe	31.970	1.125	1.22	.916	→				
4	6	Press, 15 Ton	8.340	1.125	2.44	1.832	→				
3	7	Degreaser	25.020	2.250	0	→					
3	8	Magnetic Part Insp Machine	37.530	2.250	0	→					
3	9	Phosphate Coating Unit	79.230	2.250	0	→					
3	10	Painting Machine	48.650	2.250	0	→					

TABLE III-19 TPT PROJECTILE (k=18) (FY 75 $)

$N_{i,k}$ Equ	i	Equipment Items	Equipment Unit Cost In Thousands (j=1)	Equipment Capacity/Shift In Millions (j=2)	Avg Unit Tooling Cost ($ in thousands) as $N_{i,k}=1,2,3,\ldots,\infty$ (j=3)	(j=4)	(j=5)	(j=6)	(j=7)	(j=8)	(j=9→∞)
1	1	Auto Screw Machine	$87.570	.542	4.88	3.663	3.663	3.663	3.663	2.849	→
2	2	Auto Screw Machine	73.670	.650	4.40	2.686	2.686	2.686	1.661	→	
3	3	Centerless Grinders	40.310	1.625	0	→					
4	4	Hydraulic Press (35 Ton)	16.680	1.625	2.44	1.832	→				
4	5	Press, Band Swaging	6.950	1.625	4.88	3.663	→				
3	6	Phosphate Coating Unit	79.230	1.625	0	→					
3	7	Magnetic Part Insp Machine	37.530	3.250	0	→					
3	8	Wash, Rinse & Dry Unit	25.020	3.250	0	→					
2	9	Marking Machine	3.475	3.250	0	→					
3	10	Painting Machine	31.970	3.250	0	→					

Matrix Values $X_{i,j,k}$

TABLE III-20 LINK (k=19) (FY 75 $)

$N_{i,k}$ Equ	i	Equipment Items	Equipment Unit Cost In Thousands (j=1)	Equipment Capacity/Shift In Millions (j=2)	Avg Unit Tooling Cost ($ in thousands) as $N_{i,k}=1,2,3,\ldots,\infty$ (j=3)	(j=4)	(j=5)	(j=6)	(j=7→∞)
5	1	150-Ton Blank & Form Press	$127.880	4.025	134.31	106.838	93.611	→	
5	2	#35 Mult. Slide Press	95.910	4.025	48.84	39.683	36.630	→	
5	3	Secondary Opr. OBI Press	31.970	2.683	18.32	18.320	14.245	13.736	→
5	4	Heat Treat Furnace	166.800	8.050	0	→			
5	5	Vibratory Deburring Machines	79.230	4.025	0	→			
5	6	Assembly Machine	23.630	4.025	0	→			
5	7	Ranschoff Wash & Dry	31.970	4.025	0	→			
5	8	Vapor Degreaser	16.680	4.025	0	→			
5	9	Phosphate Coating Sys.	95.910	8.050	0	→			

Matrix Values $X_{i,j,k}$

TABLE III-21 BOX (k=20) (FY 75 $)

Matrix Values $X_{i,j,k}$

$N_{i,k}$ Equ	i	Equipment Items	Equipment Unit Cost In Thousands (j=1)	Equipment Capacity/Shift In Millions (j=2)	Avg Unit Tooling Cost ($ in thousands) as $N_{i,k}=1,2,3,\ldots,\infty$ (j=3)	(j=4)	(j=5)	(j=6)	(j=7)	(j=8)	(j=9)	(j=10→∞)
6	1	Punch Press 135-150 Ton	$31.970	6.7	67.16	67.160	67.160	57.998	57.387	56.980	→	
6	2	Punch Press 60-70 Ton	16.680	6.2	9.77	9.770	9.770	9.310	9.280	9.259	9.244	→
6	3	Punch Press 20-30 Ton	8.340	8.3	4.88	4.880	4.477	4.426	4.396	→		
6	4	Press Brake 50-60 Ton	16.680	8.3	9.77	9.770	9.361	9.310	9.280	→		
6	5	Seam Welders	19.460	5.0	0	→						
6	6	Spot Welders	12.510	2.8	0	→						

NOTE: $X_{i,2,k}$ (the production equipment capacity for ammunition boxes) is expressed in rounds of ammunition instead of boxes, i.e., 67,000 boxes times 100 rounds/box = 6,700,000 rounds.

TABLE III-22 LAP (k=21) (FY 75 $)

Matrix Values $X_{i,j,k}$

$N_{i,k}$ Equ	i	Equipment Items	Equipment Unit Cost In Thousands (j=1)	Equipment Capacity/Shift In Millions (j=2)	Avg Unit Tooling Cost ($ in thousands) as $N_{i,k}=1,2,3,\ldots,\infty$ (j=3)	(j=4)	(j=5)	(j=6)	(j=7)	(j=8)	(j=9)	(j=10)	(j=11)	(j=12)	(j=13)	(j=14→∞)
5	1	Blending Units	$ 11.120	4.200	0	→										
5	2	Pelletizers	23.630	4.200	6.11	4.880	→									
7	3	Charging Machine	214.060	1.680	18.32	18.320	18.320	18.320	11.477	→						
8	4	Straight Line Loaders	87.570	1.680	9.77	9.770	9.770	9.770	4.880	→						
9	5	Auto Fuze Assemblers	48.650	.764	1.22	1.220	1.220	1.220	1.220	1.220	1.220	1.220	1.220	1.220	.333	→
5	6	Gage & Weight	87.570	4.200	14.65	12.210	→									
9	7	Can Sealer	11.120	2.800	0	→										
5	8	Marking Machine	16.680	4.200	0	→										

TABLE III-23 STEEL CARTRIDGE CASE (k=22) (FY 75 $)

Matrix Values $X_{i,j,k}$

$N_{i,k}$ Equ	i	Equipment Item: Operation	Equipment Item: Machine	Equipment Unit Cost In Thousands (j=1)	Equipment Capacity/Shift In Millions (j=2)	Equipment Unit Cost In Thousands (j=3)	Avg Unit Tooling Cost ($ in thousands) as $N_{i,k}$=1,2,3,.....,∞ (j=4)	(j=5)	(j=6)	(j=7)	(j=8)	(j=9)	(j=10)	(j=11)	(j=12 →∞)
5	1	Blank	100T(j=1)/200T(j=2)	$ 69.500	5.050	$ 139.000	12.21	7.570	→						
3	2	Grind	Auto Disc Grinder	54.000	10.160	54.000	0.50	→							
10	3	Preanneal Wash	Multistage Washer	10.000	4.870 1/	10.000	0	→							
10	4	Anneal	Annealing Furnace	150.000	4.970 1/	150.000	0	→							
10	5	Phosphate Lube& Dry	Multistage Phosphating Unit	200.000	5.720 1/	200.000	0	→							
5	6	Coin Cup	400T	278.000	3.367	278.000	2.93	2.320	2.116	→					
5	7	1st Draw	150T(j=1)/200T(j=2)	104.250	3.367	139.000	0.98	.794	.733	→					
5	8	2d Draw	100T(j=1)/200T(j=2)	69.500	3.367	139.000	0.98	.794	.733	→					
2	9	2d Draw Trim	Rotary	22.240	2.020	22.240	0.61	.610	.448	.427	.415	→			
5	10	3d Draw	100T(j=1)/200T(j=2)	69.500	3.367	139.000	0.98	.794	.733	→					
2	11	3d Draw Trim	Rotary	23.630	2.020	23.630	0.61	.610	.448	.427	.415	→			
5	12	Indent & Head	200T	139.000	2.020	139.000	1.10	1.099	.488	.458	.440	→			
2	13	Head Turn	Screw Mach 8 Spdle	102.860	1.263	102.860	6.11	6.110	6.110	6.110	3.175	3.053	3.053	2.900	→
5	14	Pierce Flash Hole	5T Horizontal	63.940	3.367	63.940	0.61	.488	.448	→					
2	15	Pretaper Trim	Rotary	23.630	2.525	23.630	0.61	.610	.448	.427	→				
5	16	Taper	65T Horizontal	83.400	3.367	83.400	1.83	1.282	1.099	→					
11	17	Preharden Wash	Multistage Washer	10.000	4.870	10.000	0	→							
11	18	Harden & Quench	1800° Tube Type	278.000	5.050	278.000	0	→							
11	19	Temper	800° Belt	79.230	5.050	79.230	0	→							
3	20	Base Anneal	50 KW Ind	208.500	5.050	208.500	0	→							
3	21	Mouth Anneal	50 KW Ind	132.050	5.050	132.050	0	→							
2	22	Final Trim	Multiple Shimmy Trim	61.160	3.367	61.160	0.61	.488	.448	→					
11	23	Rinse & Dry	Multistage Washer	10.000	4.870	10.000	0	→							
5	24	Mouth Size	20T	15.290	3.367	15.290	2.44	1.832	1.628	→					
3	25	Coating Sys.	Lacq, Varn, or Phosph	319.700	5.050	319.700	0	→							
5	26	4th Draw	150T(j=1)/200T(j=2)	104.250	3.367	139.000	0.98	.794	.733	→					
2	27	4th Draw Trim	Rotary	23.630	2.020	23.630	0.61	.610	.448	.427	.415	→			
5	28	5th Draw	200T	---	3.367	139.000	0.98	.794	.733	→					
2	29	5th Draw Trim	Rotary	---	2.020	23.630	0.61	.610	.448	.427	.415	→			
5	30	6th Draw	200T	---	3.367	139.000	0.98	.794	.733	→					
2	31	6th Draw Trim	Rotary	---	2.020	23.630	0.61	.610	.448	.427	.415	→			

1/ Equipment capacity assumed to be established to process cases requiring cupping and 3 draws (equipment processes each case 4 times at the capacity shown); $N_{i,k}$ equation 10 adjusts effective production rate to provide additional process capacity when more than 3 draws are required.

TABLE III-24 ALUMINUM CARTRIDGE CASE (k=23) (FY 75 $)

$N_{i,k}$ Equ	i	Equipment Item: Operation	Equipment Item: Machine	Equipment Unit Cost In Thousands (j=1)	Equipment Capacity/Shift In Millions (j=2)	Avg Unit Tooling Cost ($ in thousands) as $N_{i,k}$=1,2,3,.....,∞ (j=3)	(j=4)	(j=5)	(j=6)	(j=7)	(j=8→∞)
				Matrix Values $X_{i,j,k}$							
5	1	Blank & Cup	250T Mech Press	$ 228.000	8.67	11.00	→	→	→	→	→
12	2	Anneal	Annealing Oven	90.000	10.33	0	→	→	→	→	→
12	3	Wash, Rinse, & Dry; Lube & Dry	Metalwash Wash Tank/Ranschoff	195.000	10.33	0	→	→	→	→	→
5	4	1st Draw	75T Mech Press	134.200	8.67	0.88	→	→	→	→	→
5	5	2d Draw	75T Mech Press	119.200	8.67	0.88	→	→	→	→	→
13	6	Trim	V&O Trimmer	270.000	8.67	0.55	→	→	→	→	→
5	7	3d Draw	75T Mech Press	119.200	8.67	0.88	→	→	→	→	→
13	8	Trim	V&O Trimmer	251.000	8.67	0.55	→	→	→	→	→
12	9	Anneal	Annealing Oven	90.000	10.33	0	→	→	→	→	→
12	10	Wash, Rinse, & Dry; Lube & Dry	2-stage Horiz Wash/ 2-stage Horiz Wash & Dry	187.000	11.08	0	→	→	→	→	→
5	11	Pocket	175T Horiz Heading Press	318.000	8.67	0.95	→	→	→	→	→
5	12	Head	175T Horiz Heading Press	318.000	8.67	0.95	→	→	→	→	→
5	13	Initial Taper	75T 4-Bar Link Press	119.200	8.67	1.65	→	→	→	→	→
5	14	Final Taper	75T 4-Bar Link Press	119.200	8.67	1.65	→	→	→	→	→
12	15	Heat Treat	Elec Oven & Quench Tank	74.000	20.83	0	→	→	→	→	→
12	16	Age	Aging Oven	70.000	20.83	0	→	→	→	→	→
13	17	Machine Head	8-Spindle Screw Machine	92.200	2.17	5.50	5.50	4.62	4.15	→	→
13	18	Final Trim	Multiple Shimmy Trim	54.800	2.92	0.55	.44	.40	→	→	→
14	19	Mouth Anneal	Induction Annealer	118.300	10.33	0	→	→	→	→	→
14	20	Anodize	Auto-Anodize	150.000	1.08	0	→	→	→	→	→
13	21	Identification	Marking Machine	5.000	8.67	0	→	→	→	→	→
5	22	4th Draw	75T Mech Press	119.200	8.67	0.88	→	→	→	→	→
5	23	5th Draw	75T Mech Press	119.200	8.67	0.88	→	→	→	→	→
13	24	Trim	V&O Trimmer	251.000	8.67	0.55	→	→	→	→	→
12	25	Anneal	Annealing Oven	90.000	10.33	0	→	→	→	→	→
12	26	Wash, Rinse, & Dry; Lube & Dry	2-stage Horiz Wash/ 2-stage Horiz Wash & Dry	187.000	11.08	0	→	→	→	→	→
5	27	6th Draw	75T Mech Press	119.200	8.67	0.88	→	→	→	→	→

TABLE III-25 HE-T/TP-T PROJECTILE (k=24)(FY74$)

Matrix Values $X_{i,j,k}$

Equipment Item			Equipment Unit Cost In Thous.	EQUIPMENT CAPACITY/SHIFT IN MILLIONS										Avg Unit Tooling Cost ($ in Thousands)		
				Over 60mm-75mm		Over 75mm-90mm		Over 90mm-105mm		Over 105mm-120mm		Over 120mm-152mm		As $N_{i,k}$ = 1,2,3,....∞		
i	Operation	Machine	(j=1)	HE-T (j=2)	TP-T (j=3)	HE-t (j=4)	TP-T (j=5)	HE-T (j=6)	TP-T (j=7)	HE-t (j=8)	TP-T (j=9)	HE-T (j=10)	TP-T (j=11)	(j=12)	(j=13)	(j=14→∞)
1	Billet Feed	Feed Tables	28	1.44	1.44	.77	.77	.77	.77	.67	.67	.57	.57	0	0	0
2	Heat Billet	Continuous Furnace	616	1.44	1.44	.77	.77	.77	.77	.67	.67	.57	.57	0	0	0
3	Shear Slug	150T Mech Press	112	1.44	1.44	.77	.77	.77	.77	.67	.67	.57	.57	1.6	1.6	0.8
4	Descale	Water Pressure-Auto	73	1.44	1.44	.77	.77	.77	.77	.67	.67	.57	.57	0	0	0
5	Cabbage & Pierce	1000T Hyd.Press	1300	.86	.86	.77	.77	.77	.77	.69	.69	.57	.57	28.0	28.0	14.0
6	Draw	250T Hyd.Press	471	.58	.58	.58	.58	.58	.58	.48	.48	.48	.48	16.8	16.8	16.0
7	Spheroidize	Rotary Hearth	409	.86	0	.58	0	.58	0	.48	0	.48	0	0	0	0
8	Cool	Covered Conveyor	95	2.58	0	1.15	0	1.15	0	.96	0	.96	0	0	0	0
9	Clean	SandBlast Mach	69	.86	0	.58	0	.58	0	.48	0	.48	0	0	0	0
10	Center	Duplex Lathe	55	.72	.72	.58	.58	.58	.58	.08	.08	.08	.08	0.6	0.6	0.6
11	Contour Turn	Tracer Lathe Auto	95	.10	.18	.10	.18	.10	.18	.08	.12	.08	.12	1.2	1.2	1.2
12	Turn End	Tracer Lathe Auto	95	.10	.18	.10	.18	.10	.18	.08	.12	.08	.12	0.6	0.6	0.6
13	Wash	Conveyorized	5	1.44	1.44	.77	.77	.77	.77	.48	.48	.48	.48	0	0	0
14	Heat Treat	Cont Oven & Quench Tank	364	1.44	0	.77	0	.77	0	.48	0	.48	0	6.0	6.0	6.0
15	Anneal & Cool	Oven & Cool Tunnel	364	1.44	0	1.44	0	1.44	0	.96	0	.96	0	0	0	0
16	Shot Blast	Shot Blast Equip	69	.58	0	.58	0	.58	0	.48	0	.48	0	0	0	0
17	Nose	500T Hyd. Press	169	.86	.86	.77	77		.77	.48	.48	.48	.48	20.0	20.0	18.0
18	Bore, Face, & Chamfer	P&J Auto	168	.38	.38	.36	.36	.36	.36	.29	.29	.29	.29	1.2	1.2	1.2
19	Finish Turn	Tracer Lathe	67	.09	.14	.08	.15	.08	.15	.08	.12	.08	.12	1.2	1.2	1.2
20	Finish Rear	Tracer Lathe	67	.09	.14	.11	.18	.11	.18	.08	.12	.05	.10	1.6	1.6	1.6
21	Knurl Band(s)	Spec Knurl Mach	12	1.15	1.15	.77	.77	.77	.77	.29	.29	.25	.25	0	0	0
22	Notch Nose	Mill Index Auto	17	.38	.38	.22	.22	.22	.22	.19	.19	.19	.19	1.3	1.3	1.3
23	Tap Nose	Thread Taper Auto	17	.29	.29	.22	.22	.22	.22	.19	.19	.10	.10	0.3	0.3	0.2
24	Stamp	Stamping Mach	9	.86	.86	.77	.77	.77	.77	.48	.48	.48	.48	1.5	1.5	1.5
25	Grind	Centerless Grinder	54	.86	.86	.77	.77	.77	.77	.48	.48	.48	.48	.6	.6	.6
26	Wash	Hydo Pres. Test & Wash Conv.	16	.86	.86	.77	.77	.77	.77	.77	.77	.77	.77	0	0	0
27	Weld Back Plate	Rotary Seam & Anneal	73	.48	0	.48	0	.48	0	.48	0	0	0	.6	.6	.6
28	Assemble Band	Banding Mach	33	.43	.43	.38	.38	.36	.36	.29	.29	.29	.29	0	0	0
29	Machine Band	Lathe Semi-Auto	84	.43	.43	.38	.38	.38	.38	.19	.19	.29	.29	0.6	0.6	0.3
30	Wash & Paint	Bond.Elec,Paint & Bake	230	2.61	2.61	1.54	1.54	1.54	1.54	1.44	1.44	1.12	1.12	89.0	89.0	89.0
31	Load Coil Cr.	Coil Craddle	9	3.07	3.07	3.07	3.07	3.07	3.07	3.07	3.07	3.07	3.07	0	0	0
32	Straighten	Coil Straightener	10	3.07	3.07	3.07	3.07	3.07	3.07	3.07	3.07	3.07	3.07	0	0	0
33	Blank	50T Mech Press	69	3.07	3.07	3.07	3.07	3.07	3.07	3.07	3.07	3.07	3.07	1.6	1.6	1.6
34	Tumble	Mech Deburr Tumble	6	3.07	3.07	3.07	3.07	3.07	3.07	3.07	3.07	3.07	3.07	0	0	0
35	Tubing Shape & Cutoff	Screw Mach	79	.57	.57	.57	.57	.57	.57	.57	.57	.57	.57	0.8	0.8	0.8

TABLE 111-26 AP-T/TP-T PROJECTILE (k=25)(FY74$)

Matrix Values $X_{i,j,k}$

i	Equipment Item: Operation	Equipment Item: Machine	Equipment Unit Cost In Thousands (j=1)	Equipment Capacity/Shift In Millions: Over60-75mm AP-T (j=2)	Over60-75mm TP-T (j=3)	Over75-90mm AP-T (j=4)	Over75-90mm TP-T (j=5)	Over90-120mm AP-T (j=6)	Over90-120mm TP-T (j=7)	Avg Unit Tooling Cost ($ in Thous)as $N_{i,k}$=1,2,3,...,∞ (j=8)	(j=9)	(j=10 → ∞)
1	Saw Slug	Auto Power Saw	35	.08	.12	.06	.10	.05	.10	0	0	0 →
2	Center Slug	Duplex Lathe	54	.23	.25	.23	.25	.23	.25	0	0	0 →
3	Rough Turn OD & Base	6 Spindle Screw Mach	56	.13	.16	.10	.12	.06	.08	0.3	0.3	0.3 →
4	Rough Turn Nose	6 Spindle Screw Mach	56	.12	.15	.10	.12	.03	.05	0.6	0.6	0.6 →
5	Turn Body Relief&Seats	Tracer Lathe	96	.14	.16	.12	.14	.06	.08	0.8	0.8	0.8 →
6	Finish Nose	Hollow Spindle Tracer	96	.17	.20	.12	.14	.08	.10	0.6	0.6	0.6 →
7	Wash	Conveyor Degrease	18	.24	.24	.24	.24	.24	.24	0	0	0 →
8	Heat Treat	Furnace Conveyorized	528	1.18	0	1.00	0	.89	0	0	0	0 →
9	Quench	Tanks Conveyorized	200	1.18	0	1.00	0	.89	0	0	0	0 →
10	Descale & Clean	Sand Blast Machs	138	.45	0	.41	0	.38	0	0	0	0 →
11	Tap Tracer Hole	Radial Drill w/Tap	13	.16	.16	.15	.15	.13	.13	0.1	0.1	0.1 →
12	Turn Nose	Hollow Spindle Tracer	56	.40	.50	.30	.36	.19	.25	0.6	0.6	0.6 →
13	Grind Bourrelet	Centerless Grinder	85	.87	.87	.50	.50	.19	.19	0	0	0 →
14	Wash & Knurl	Conveyorized Washer	17	.41	.41	.41	.41	.38	.38	0	0	0 →
15	Seat 1st Band	Banding Mach	33	.49	.49	.36	.36	.29	.29	0	0	0 →
16	Seat 2d Band	Banding Mach	33	0	0	0	0	.29	.29	0	0	0 →
17	Turn Bands	Lathe Semi-Auto	84	1.44	1.44	1.40	1.40	1.15	1.20	0.2	0.2	0.2 →
18	Wash	Degreaser	18	.24	.24	.24	.24	.24	.24	0	0	0 →
19	Glue Windshield	Glue & Dry Racks	0	0	0	.77	.77	.77	.77	12.0	12.0	12.0 →
20	Assemble Windshield	Glue & Hold Racks	0	0	0	.38	.38	.30	.30	36.0	36.0	36.0 →
21	Wash,Paint & Bake	Bonderize,Electro Paint & Bake	233	1.74	1.74	1.50	1.50	.53	.53	30.0	30.0	30.0 →
22	Mark	Power Marking Roller	13	1.09	1.09	1.00	1.00	.53	.53	0.6	0.6	0.6 →
23	Tubing Shape & Cutoff Band	Screw Mach	79	.57	.57	.57	.57	.57	.57	0.8	0.8	0.4 →
24	MeltAlIngot-Windshield	Melting Furnace	50	0	0	.30	.30	.30	.30	0	0	0 →
25	Hold	Crucible Container	12	0	0	.19	.19	.19	.19	0	0	0 →
26	Pour	400 T Casting Mach	176	0	0	.19	.19	.19	.19	6.0	6.0	6.0 →
27	Trim	35 T OBI Mech Press	32	0	0	.33	.33	.33	.33	2.5	2.5	2.5 →
28	Mach Skirt	Lathe	56	0	0	.25	.25	.25	.25	0.8	0.8	0.4 →
29	Mach Concentricity	Vertical Mill	28	0	.25	.25	.25	.25	1.00	1.00	0.8	0.8 →
30	Degrease	Vapor-Conveyorized	18	0	.51	.51	.51	.51	0	0	0	0 →

TABLE III-27 LAP-METAL CARTRIDGE CASE AMMO (k=26)(FY = (FY74$)

Equipment Item			Equipment Unit Cost In Thousands	Matrix Values $X_{i,j,k}$ Equipment Capacity/Shift in Thousands					Average Unit Tooling Cost ($ in Thous) as $N_{i,k}$ = 1,2,3,...,∞
i	Operation	Machine	(j=1)	Over60-75mm (j=2)	Over75-90mm (j=3)	Over90-105mm (j=4)	Over105-120mm (j=5)	Over120-152mm (j=6)	(j=7 → ∞)
1	Screen to Melt	Fill Process Equipment	156	8.50	4.60	1.86	1.50	1.89	0 →
2	Hold & Flaker	Flaker&Dopper Kettle Sys	92	1.85	1.21	.41	.33	.41	0 →
3	Clean Shell&Prezone	Vac. Paint & Weigh	16	.96	.96	.80	.80	.80	6.0 →
4	Coat Funnels	Paint	16	.96	.96	.96	.96	.96	6.5 →
5	Load Funnels&Pour	Volumetric Equipment	36	1.85	1.21	.41	.33	.41	0 →
6	Probe	Multi Probe Equipment	28	1.21	.88	.75	.60	.48	0 →
7	Knockout Riser&Clean	Funnel Pull & Clean Equipment	17	.96	.60	.58	.54	.48	0 →
8	Drill&Clean Threads	Multi Drill & Vacuum	37	.96	.70	.60	.54	.48	0 →
9	Inspect&Weigh	Exacto Scales	54	.96	.73	.60	.54	.48	0 →
10	Assem Tracer	Assem & Stake Equipment	23	.80	.80	.75	.75	.70	0.6 →
11	Assem Fuze	Fuze Torque & Stake	20	.96	.82	.80	.75	.70	6.5 →
12	Cool	Conveyor	87	1.06	.96	.60	.54	.50	0 →
13	Inspect/Gage Thread	Auto Thread Gage	53	1.20	1.00	.80	.75	.75	6.0 →
14	Stencil	Power Roller	13	.77	.70	.60	.50	.45	1.2 →
15	Assem Primer	Assem & Stake Equipment	16	1.54	1.20	1.00	.75	0	0 →
16	Fill&Weigh Case	Auto Fill & Weigh	63	1.20	1.20	.60	.33	0	6.0 →
17	Propellant Feed	Auto Feed Equipment	39	4.52	4.40	2.20	.20	3.6	6.0 →
18	Apply Sealer	Auto Brush Coat	5	.81	.77	.70	.60	.60	0.6 →
19	Assem & Crimp	Crimping Machine	30	.81	.77	.70	0	0	0 →
20	Mark & Gage	Auto Gage & Mark	58	.77	.70	.60	.60	0	0 →
21	Cut Spacer	Cardboard Tube Cutter	6	0	0	0	.58	0	1.6 →
22	Assem Igniter&Washer	Washer Press & Die	17	0	0	0	2.20	0	2.0 →
23	Assem Spacer&Cap	20 T Mech Press	13	0	0	0	.86	0	1.0 →
24	Form Case Top Curl	Case Press	20	0	0	0	0	.96	1.2 →
25	Assem Case&Adapter	Special Assy Equipment	14	0	0	0	0	.48	1.6 →
26	Load Primer Tube	Index Equipment	20	0	0	0	0	.38	0 →
27	Load Propellant	Hand Fixture	1	0	0	0	0	.38	0.3 →
28	Apply Initiator	Index Equipment	13	0	0	0	0	.75	1.2 →
29	Apply Cement&Press Cap	20 T Mech Press	13	0	0	0	0	.38	1.0 →

TABLE III-28 LAP-COMBUSTIBLE CARTRIDGE CASE AMMO (k=27)(FY 74$)

Equipment Item			Equipment Unit Cost In Thousands	Matrix Values $X_{i,j,k}$: Equipment Capacity/Shift In Millions				
i	Operation	Machine	(j=1)	Over 60-76mm (j=2)	Over 75-90mm (j=3)	Over 90-105mm (j=4)	Over 105-120mm (j=5)	Over 120-152mm (j=6)
1	Screen	Gyro Screener	34.9	2.248	1.217	.492	.397	.500
2	Melt Explosive	Melt Grid & Kettle	223.4	2.248	1.217	.492	.397	.500
3	Pour Explosive	Volumetric Loader	85.0	2.000	2.000	2.000	2.000	2.000
4	Probe	Probe Equip	28.0	1.000	1.000	.800	.600	.600
5	Remove Funnel	Funnel Puller	2.8	1.400	1.200	1.000	1.000	1.000
6	Remove Riser	Riser Knockout	2.8	.500	.500	.500	.500	.500
7	Drill	Explosive Drill	2.1	1.200	.875	.750	.675	.600
8	Assem Projectile	Auto Proj Assy Equip	128.4	.750	.525	.500	.300	.300
9	Loctite	Loctite Detector	14.0	.125	.125	.125	.125	.125
10	Case Installation	Installation Equip	7.0	.200	.200	.200	.200	.200
11	PD Assem Check	Auto Checking Equip	65.6	.350	.350	.350	.350	.350
12	Gage Chamber	Profile & Alignment Equip	43.3	.625	.500	.375	.248	.248
13	Pack In Styrofoam	Pack, Tape & Stencil Equip	30.7	1.000	.800	.600	.480	.480
14	Final Pack & Strap	Can Stenciler & Auto Strapper	76.8	1.000	.760	.500	.360	.360

NOTE: The Tooling, Installation and Transportation, and TME costs are included in the equipment cost.

TABLE 111-29 STEEL CARTRIDGE CASE (k=28)(FY74$)

Equipment Item			Matrix Values $X_{i,j,k}$							
			Equipment Unit Cost In Thousands	Equipment Capacity/Shift In Millions				Avg Unit Tooling Cost ($ In Thous)as $X_{i,k}$=1,2,3,..,		
i	Operation	Machine	(j=1)	Over60-75mm (j=2)	Over75-90mm (j=3)	Over90-105mm (j=4)	Over105-120mm (j=5)	(j=6)	(j=7)	(j=8 → ∞)
1	Blank	600 T Press	249	3.07	3.07	3.07	1.50	16.0	16.0	8.0 →
2	Mark,Wash&Coat	25 T OBI Press	28	1.15	.91	1.54	1.48	2.4	2.4	1.2 →
3	Cup	500 T Press	250	1.15	.65	.77	.53	36.0	36.0	18.0 →
4	Trim Cup	Chucker	36	.77	.34	.77	.34	1.2	1.2	.6 →
5	Anneal,Pickle&Coat	Conveyorized Lines	5.73	5.73	4.10	4.14	3.48	89.0 →	→	→
6	1st Draw&Wash	200 T Hyd Press	83	1.15	.77	.86	.40	10.8	10.8	5.4 →
7	2d Draw&Wash	150 T Hyd Press	166	1.10	.91	.91	.62	10.8	10.8	5.4 →
8	3d Draw&Wash	150 T Hyd Press	166	1.02	.72	.86	.26	12.5	12.5	6.3 →
9	1st Draw Trim	V&O Trimmer Auto	31	1.44	1.39	1.39	1.20	0 →	→	→
10	4th Draw&Wash	100 T Hyd Press	132	1.02	.67	.79	.20	14.2	14.2	7.1 →
11	2d Draw Trim	V&O Trimmer Auto	31	1.44	1.39	1.39	1.20	0 →	→	→
12	Coin Prehead	1500 T Hyd Press Dual Feed	266	.69	.69	.69	.69	5.0 →	→	→
13	Head	2800 T Hyd Press	676	.69	.69	.69	.69	6.0 →	→	→
14	5th Draw	100 T Hyd Press Dial Feed	132	.60	.60	.60	.60	14.2	14.2	7.1 →
15	Machine Head&Wash	Chucker	35	.47	.34	.38	.30	6.8 →	→	→
16	Anneal Mouth	200KW Induction	70	.80	.80	.80	.80	1.0 →	→	→
17	Taper Mouth	250 T Press Dial Feed	212	.92	.44	.92	.44	22.4	22.4	10.0 →
18	Trim Mouth	V&O Trimmer Auto	31	1.39	1.39	1.39	1.39	0 →	→	→
19	Finish Primer Hole	Dual Drill Press	18	.69	.54	.54	.50	.6 →	→	→
20	Stamp	40 T Dial Feed Press	38	.82	.82	.82	.82	.5 →	→	→
21	Paint	Bonderize, Electro Static Paint	230	.96	.96	.96	.96	10.0 →	→	→

TABLE III-30 STEEL CARTRIDGE CASE, SPIRAL WRAP (k=29)(FY74$)

i	Operation	Machine	Equipment Unit Cost In Thousands (j=1)	Equipment Capacity/Shift In Millions: Over 60-90mm (j=2)	Equipment Capacity/Shift In Millions: Over 90-120mm (j=3)	Avg Unit Tooling Cost ($ in Thous) as $N_{i,k}$= 1,2,3,..., ($j=4 \rightarrow \infty$)
			Matrix Values $X_{i,j,k}$			
	Body					
1	Coil Craddle Load	38" Craddle	16	2.59	1.30	0
2	Straighten	38" Straightener	16	2.59	1.30	0
3	Blank Double	Lg Bed Mech Press	168	2.59	1.30	18.0
4	Bonderize-Varnish-Bake	Bonderize Electro Paint-Oven	504	5.18	2.60	0
5	Roll Form	Rollers	25	.63	.38	5.0
6	Spin Flange	Lathe	28	.63	.38	1.6
	Base & Collar					
7	Load Feed Tables	Roller Tables	113	1.04	.69	0
8	Multi Burn Disc	Multi Head Tracer Burners	28	.86	.58	1.2
9	Heat Treat	Furnace	50	2.59	1.73	0
10	Forge	1000T Mech Press	335	.86	.58	19.0
11	Vapor Descale	Water Jet Cabinet-Conveyorized	19	2.59	1.73	0
12	Cool-Pickle	Oven Hooded-Conveyorized	50	2.59	1.73	0
13	Machine Face	Chucker-Auto Turret	93	.44	.38	2.4
14	Machine Back	Chucker-Auto Turret	93	.44	.38	2.6
15	Machine Grove	Collet Lathe	56	.63	.58	2.2
	Assembly					
16	Assemble & Size	150T Hyd Press-Rotary Feed	242	.63	.63	11.0
17	Final Touch-up Paint	Water Fall Booth	7	2.60	2.60	0.6

TABLE III-31 BRASS CARTRIDGE CASE (k=30)(FY 74$)

			Matrix Values $X_{i,j,k}$							
Equipment Item			Equipment Unit Cost In Thousands	Equipment Capacity/Shift in Millions				Avg Unit Tooling Cost ($ in Thous) as $N_{i,k}$ = 1,2,3,.....		
i	Operation	Machine	(j=1)	Over60-75mm (j=2)	Over75-90mm (j=3)	Over90-105mm (j=4)	Over105-120mm (j=5)	(j=6)	(j=7)	(j=8 ——→ ∞)
1	Purchase Blank		0	0	0	0	0	8.0	8.0	5.6 ——→
2	Cup	500 T Hyd Press	129	1.08	1.08	1.08	.53	10.0	10.0	8.8 ——→
3	Anneal & Pickle	Cont Basket Conveyor-4 Lines	573	3.81	3.35	3.64	1.48	89.0	89.0	89.0 ——→
4	1st Draw	250 T Hyd Press	169	.85	.72	.85	.40	11.0	11.0	5.4 ——→
5	2d Draw	200 T Hyd Press	163	1.05	.91	1.09	.32	11.0	11.0	5.4 ——→
6	3d Draw	150 T Hyd Press	161	.83	.72	.91	.26	12.0	12.0	6.0 ——→
7	4th Draw	100 T Hyd Press	127	.85	.59	.79	.20	15.0	15.0	7.1 ——→
8	Wash & Inspect	5 Wash Units - 1/Press	135	3.58	2.94	3.64	1.18	20.0	20.0	20.0 ——→
9	Trim Case	V&O Trimmer Auto	62	.72	.73	.72	.70	0.1	0.1	0.1 ——→
10	Coin Head & Indent	2800 T Hyd Press Dial Feed	676	.82	.82	.82	.58	10.0	10.0	9.5 ——→
11	Anneal Mouth	Liqued Anneal-Converorized	59	.82	.51	.48	.48	10.0	10.0	10.0 ——→
12	Taper Mouth	150 T Hyd Press Dial Feed	176	.73	.73	.73	.73	25.0	25.0	12.0 ——→
13	Mach Head & Primer Hole	4 Spindle Chucker	118	.55	.48	.40	.38	5.6	5.6	2.0 ——→
14	Final Trim Mouth	2 Sta Drill & Reamer	19	.40	.40	.40	.40	1.4	1.4	.7 ——→
15	Anneal	Continuous Furnace	58	.96	.96	.96	.96	6.0	6.0	6.0 ——→
16	Stress Relieve	Low Temp Furn-Continuous	51	.96	.96	.96	.70	0	0	0 ——→
17	Insp & Stamp Head	40 T Hyd Press Dial Feed	29	.83	.82	.83	.70	8.2	8.2	4.1 ——→

TABLE 111-32 COMBUSTIBLE CARTRIDGE CASE (k=31)(FY74$)

MATRIX VALUES $X_{i,j,k}$

i	EQUIPMENT ITEM	Equipment Unit Cost In Thousands (j=1)	EQUIPMENT CAPACITY/SHIFT IN MILLIONS 60-76mm (j=2)	Over 76-90mm (j=3)	Over 90-105mm (j=4)	Over 105-120mm (j=5)	Over 120-152mm (j=6)
1	Batching Tank, 2K Gal.	25	.077	.071	.071	.067	.100
2	Hydropulping, 2K Gal.	25	.077	.071	.071	.067	.100
3	Storage Tank, 30K Gal.	50	.026	.024	.024	.022	.033
4	Felting Complement	50	.026	.024	.024	.022	.033
5	Molding Press, 600 P.S.I.	[illegible]	.0056	.0053	.0050	.0048	.0071
6	Laboratory	35	.167	.167	.167	.167	.167

MATRIX VALUES $X_{i,j,k}$

i	EQUIPMENT ITEM	Avg Unit Tooling Cost ($ in Thousands) As $N_{i,k}$ = 1,213,..., ∞ 60mm (j=7)	Over 60-76mm (j=8)	Over 76-90mm (j=9)	Over 90-105mm (j=10)	Over 105-120mm (j=11)	Over 120-152mm (j=12)
1	Batching Tank, 2K Gal.	51	57	64	69	83	50
2	Hydropulping, 2K Gal.	51	57	64	69	83	50
3	Storage Tank, 30K Gal.	40	46	51	55	66	40
4	Felting Complement	62	67	77	83	100	60
5	Molding Press, 600 P.S.I.	111	111	113	114	119	70
6	Laboratory	5	5	5	5	5	5

TABLE III-33 FUSE-TANK AMMO (k=32)(FY74$)

i	Equipment Item	Equipment Unit Cost In Thousands (j=1)	Equipment Capacity/Shift In Millions (j=2)	Avg Unit Tooling Cost (In Thous) as $N_{i,k} = 1,2,3,\ldots\infty$ (j=3 → ∞)
		Matrix Values $X_{i,j,k}$		
1	Auto Lathe 6 SPL 7/16"	31.0	.605	1.96
2	Auto Lathe 6 SPL 1-1/4"	52.0	.323	0
3	Auto Lathe 6 SPL 5-1/2	100.0	.605	0
4	Auto Lathe 4 SPDL 2"	64.0	.323	0
5	Auto Lathe 1 SPDL 17/64"	65.0	.484	1.24
6	Auto Lathe 1 SPDL 17/64"	32.5	.806	.57
7	Auto Lathe 1 SPDL 17/64"	32.5	.968	.38
8	Auto Lathe 1 SPDL 1/2"	32.5	.806	.18
9	Auto Lathe 1 SPDL 1/2"	32.5	.691	.22
10	Auto Lathe 1 SPDL 1/2"	32.5	.605	.29
11	Auto Lathe 1 SPDL 3/4"	26.0	.323	.25
12	Auto Lathe 1 SPDL 1/4"	34.0	2.419	0
13	Press 15T Mech	8.0	14.515	2.79
14	Press 18T Mech	27.0	14.515	19.24
15	Press 18T Mech	18.0	9.677	15.84
16	Press 30T Mech	32.0	9.677	21.29
17	Milling Mach Horiz	7.0	14.515	0
18	Milling Mach Semi-Auto	3.5	.605	.85
19	Spcl Drill Mach 5-SPDL	13.0	.605	0
20	Spcl Drill Mach 5-SPDL	13.0	.806	1.07
21	Spcl Rotary Trans 8 Sta	64.0	.806	0
22	Spcl Rotary Trans 8 Sta	64.0	.605	0
23	Spcl Rotary Trans 8 Sta	64.0	.484	0
24	Spcl Rotary Trans 10 Sta	80.0	.484	0
25	Coil Forming Mach	14.0	1.613	2.60
26	Spcl Rotary Trans 4 Sta	83.0	.968	0
27	Spcl Rotary Trans 6 Sta	40.0	.968	0
28	Press Staking	.4	.131	2.28
29	Press Staking	.9	.104	2.60
30	Press Staking	1.2	.173	0
31	Press Staking	1.2	.086	2.42
32	Press Staking	1.2	.188	1.33
33	Bench Press Hyd	3.0	.173	4.08
34	Arbor Press	.1	.131	1.15
35	Welder	2.1	.173	2.39
36	Air Screw Driver	5.0	.131	.70
37	Air Powered Driver	5.0	.058	1.30
38	Air Powered Driver	5.0	.104	.90
39	Riveting Mach	2.2	.131	0
40	Marking Mach	8.0	.259	3.26

Table III-34. Cost Equation Sequences of Solution - N_f, $Y_{i,k}$, Y_k, and Y_f 1/

Component	Equation Numbers
1. Projectiles (k=16,17,18)	
a. IPE	16, 21
b. Initial Tooling	24, 28
c. TME	
(1) k=16,17	30
(2) k=18	31
2. Link (k=19)	
a. IPE	16, 21
b. Initial Tooling	24, 28
c. TME	32
3. Box (k=20)	
a. IPE	16, 21
b. Initial Tooling	24, 27
c. TME	33
4. LAP (k=21)	
a. IPE	16, 22
b. Initial Tooling	24, 28
c. TME	34
5. Steel Cartridge Case (k=22)	
a. IPE	
(1) $L \leq 3.5$ in., $D \leq 40$mm	17, 21
(2) $L > 3.5$ in., $D = 20$mm	18, 21
(3) $L > 3.5$ in., $20\text{mm} < D \leq 40$mm	19, 21
b. Initial Tooling	
(1) $L_c \leq 3.5$ in., $D \leq 40$mm	25, 28
(2) $L_c > 3.5$ in., $D = 20$mm	25, 28
(3) $L_c > 3.5$ in., $20\text{mm} < D \leq 40$mm	25, 29
c. TME	35
6. Aluminum Cartridge Case (k=23)	
a. IPE	20, 21
b. Initial Tooling	26, 28
c. TME	35
7. Fuze	
a. IPE	15, 23
b. Initial Tooling	NA
c. TME	36

1/ Equations for $N_{i,k}$ are listed in Tables III-17 through III-24.

C. RECURRING INVESTMENT

1. Data Collection

ARMCOM ammunition procurement involves a mixture of ammunition obtained from contractor owned contractor operated (COCO) plants, Government owned contractor operated (GOCO) plants, and Government owned Government operated (GOGO) arsenals. However, most ammunition is procured from GOCO's which support the Government's ammunition needs through the manufacture of propellants, explosives, metal parts, small arms, bag loading, and LAP. Each GOCO is operated by a major US corporation which was selected on the basis of proven success in the management of large production operations. It is a common practice in the Army's ammunition world to find a variety of GOCO's, GOGO's and private companies contributing components toward the final production of a round of ammunition. Thus, the collection of cost and production data involves the accumulation of data generated by a variety of manufacturers.

Data collected for this study were taken from contract-price records and production-delivery schedules available in the ARMCOM Directorates of Procurement and Production and Quality Assurance.

a. Procurement Cost Data

The Summary of Orders and Costs of Deliveries is a record of contract pricing which lists the production quantities and costs for the components ordered. This record is created from a number of source documents furnished by producers and ordering officials. It includes monthly costs and performance reports from the GOCO's, contracts and delivery schedules for private contractors, and funding documents awarded to GOGO's. The summarization of data includes cost and delivery data incurred during the current reporting period and cumulative cost and delivery data incurred from the inception of the procurement order. Data provided are:

- Current Deliveries
  - Date of deliveries
  - Quantity delivered
  - Total cost of deliveries
  - Funded cost of deliveries
  - Unfunded or Government furnished material cost
  - Funded unit cost
- Total deliveries to date
  - Cumulative deliveries from inception of order
  - Average unit cost
  - Total cost
  - Total unfunded or Government furnished material cost
  - Total funded cost
  - Funded unit cost

LAP, projectiles, explosive fill, primers, fuzes, cases, propellants and links are analyzed in this study. Tracking quantities and costs from the Summary of Orders and Costs of Deliveries required the analysts to review approximately 3,000 line entries. Capturing quantities and costs for a specific round of ammunition required collecting data according to the components of the round and any related LAP operation. Data were collected from fiscal year 1957 through 1975.

b. Production Quantity Data

The source documents used to capture procurement data were production-delivery schedules and ammunition-data cards. The production-delivery schedule is a monthly report that is prepared by each active GOCO and GOGO. The report provides monthly production rates and final acceptance rates of each item. The ammunition data card is a delivery and acceptance report reflecting quantities shipped by a contractor, GOCO or GOGO.

Collecting production delivery data required an analysis of approximately 10,000 line entries. Analyzed production rates encompassed the review of data generated from fiscal years 1957 through 1975. The review disclosed many instances in which production data were available but corresponding costs could not be collected because of the unavailability of the applicable Summary of Orders and Costs of Deliveries. Annex A (ref 92) of ref 95 demonstrates these differences. Production quantities without corresponding costs were collected to determine breaks in production.

c. Independent Variables

The independent variables reflected in this study represent a start at finding variables which may be used by a cost estimator to predict recurring ammunition costs. Finding variables which cover the entire spectrum of round sizes is difficult. At the outset of the study, a potential independent-variable list was developed through a coordinated effort between Cost Analysis, Research and Development, and Systems Analysis personnel. The following tables list the potential characteristics and classifications which represent those variables deemed by this group to have high potential as cost drivers.

POTENTIAL CARTRIDGE CHARACTERISTICS

Weight

- Cartridge
- Projectile
- Propellant
- Fuze
- Primer

Volume

Complexity

- Number of parts
- Type of manufacturing

Length

Diameter

Muzzle Velocity

Kinetic Energy

Range

- Maximum
- Effective

Chamber Pressure

Muzzle Impulse

Desired Target Effect

Lethal Area at 2/3 Maximum Range

Vulnerable Area

Time of Flight

POTENTIAL CLASSIFICATION OF ITEMS AND COMPONENTS

Weapon-Operation Concept

- Recoilless, recoil, gas recoil, and soft recoil

Material Differences

- Steel versus high fragmentation projectiles
- Steel versus brass versus aluminum cartridge cases or caseless
- Single- versus double- versus triple-base propellants

Type of Fill

- TNT, Comp B, Comp A3, etc.

Fuzes

- Impact--point or base detonating
- Time--pyrotechnic, mechanical time, electrical time
- Proximity--reliability and accuracy

Improved Conventional Munitions

- Number of submunitions
- Complexity of submunitions
- Target effects

Munitions-Kill Mechanism

Armor-piercing discarding sabot (APDS)
High-explosive plastic (HEP)
High-explosive antitank (HEAT)
High Explosive (HE)

Of the potential characteristics and classifications, the following characteristics were selected, and quantitative data have been gathered by complete round or ammunition component. The independent variables are segregated by total round and major components. The variables are further segregated into physical characteristics, performance characteristics, and combinations of physical and performance characteristics.

TOTAL ROUND CHARACTERISTICS

Physical	Performance	Combinations of Physical and Performance
Weight	Muzzle velocity	Kinetic energy
Diameter (bore size)	Range	Momentum
Volume	Chamber pressure	
Length		

COMPONENT PHYSICAL CHARACTERISTICS

LAP

Projectiles

Weight
Total
Explosive

Cases

Length

Propellants

Weight

Primers

Fuzes

Number of Parts

There are several independent variables which would appear to be good cost drivers. These variables are expressions of target effect, e.g., armor-penetration, fragmentation effect, etc. Measures of armor-penetration, in conjunction with equations presented in section IVC, can be used to estimate armor piercing projectile costs. Measures of fragmentation are considered to be prime howitzer projectile cost drivers.

There are several component characteristics which are known to provide good CER's. An example is primer cost as a function of primer weight. Such independent variables are useless to the estimator developing an IPCE in the concept-formulation phase or the validation phase of the life cycle. Hence, use of such independent variables was not considered. Two component characteristics used frequently in this study are projectile mass and bore size. Use of these component characteristics is defended on the grounds that target effects can be used to infer projectile mass and bore size; therefore, they become legitimate independent variables.

The following are definitions of variables used in the study:

Weight includes the nominal weight in pounds of the complete round and all components with a standard fuze. Fixed rounds include total cartridge weight; semi-fixed and separate rounds include the weights of the total separated components, e.g., projectile, case, and propellant.

Range is the maximum distance in yards, or the effective distance which the round can perform its designed function when range is not a criterion. It is the approximate range expected when firing a stationary weapon at the most favorable elevation, under normal atmosphere conditions, with both weapon and projectile impact at sea-level altitude.

Bore Size is the diameter of the bore across the rifling flats of the weapon firing the ammunition.

Muzzle Velocity is the speed of the projectile measured in feet per second.

Projectile Mass is that value determined by dividing projectile weight by the force of gravity, which is 32.2 feet per second per second.

Momentum is a product of projectile mass and muzzle velocity.

Kinetic Energy is the product of muzzle velocity squared and 1/2 the mass.

Chamber Pressure is the pressure limit developed by the propelling charge to produce a specified projectile-muzzle velocity.

In addition to the independent variables developed for the physical and performance characteristics, consideration was given to the cost-quantity relationship. Costs may be materially impacted as a result of the quantity of a given component produced in a given year.

Annex D details the independent variable values used in this study for complete rounds and components as cross indexed one to another.

2. Analysis of Learning

Application of cost improvement curves adds great flexibility to the estimator's tools. It allows CER's to be applied easily to a wide range of procurement quantities with relatively simple calculations. Therefore, it became a prime objective of the ammunition cost research project to develop CER's which could be coupled to learning rates where-ever possible. To accomplish this objective, several critical questions had to be answered.

What are the proper learning rates to be used for each component assuming that there will probably be more than one producer?

Does level off occur? If it occurs, at what point does it occur?

Do variations in production rates influence the theoretical first-unit cost?

Do variations in production rates influence the learning rate?

Do breaks in production require that adjustments be made for loss of learning in ammunition cost estimates?

a. Methods Used for the Analysis

(1) Normalization of the data for inflation

The historical cost data contained in Annex A were normalized to FY 74 dollars because the final inflation rate for FY 75 was not available at the time the data were normalized. ARMCOM Circular 37-1, dated 9 Jun 75, "Inflation and Price Escalation Instruction for Ammunition," was used for fiscal years 1960 and following. Before FY 60, Wholesale Price Indexes for metal and metal products were applied. These were found in the MICOM publication, dated 6 May 74, "Historical Inflation Indices". The indexes actually used are:

FY	Under 30mm	Over 30mm	FY	Under 30mm	Over 30mm
75	0.83	0.83	66	1.49	1.49
74	1.00	1.00	65	1.53	1.62
73	1.12	1.10	64	1.55	1.68
72	1.18	1.15	63	1.57	1.73
71	1.23	1.22	62	1.58	1.76
70	1.26	1.28	61	1.59	1.78
69	1.41	1.35	60	1.60	1.80
68	1.47	1.42	59	1.59	
67	1.55	1.46	58	1.66	
			57	1.68	

(2) Selection of data for calculation of consolidated learning rates

The following criteria were established for selecting historical cost data for running learning curves.

The component must have two or more consecutive years of production cost history.

When production breaks of two or more years occurred, only the production cost history prior to the break was used.

When a production break of one year occurred and a reduced cost was experienced after the production break, the break was ignored.

When the constant-year cost data for FY 73 through FY 75 appeared inordinately high compared to prior years, only production cost history for FY 72 and before was used.

Learning curves were developed for each producer by item within each component. The following criteria were then established for determining which learning curves would be used in developing a composite learning rate.

Individual learning curves of 100 percent or higher were excluded because cost increases are attributed to causes other than learning.

Extreme learning curves in the lower range were also eliminated. Generally, this excluded any learning curves less than 80 percent.

(3) Calculations of the composite learning rate

Once the learning results had been screened using the criteria outlined above, composite learning rates by component were determined. The regression form used in developing the composite learning rate is:

$$Y = AX^B$$

To normalize the cost data for each learning curve, the theoretical first-unit cost was set equal to 1.0. The ratio of 1.0 to the original theoretical first-unit cost was applied to the actual lot average unit costs resulting in normalized lot average unit costs. Since the theoretical first-unit costs were set equal to 1.0, the regression form above reduced to:

$$Y = X^B$$

Based upon linear regression theory,

$$B = \frac{\sum \text{LnY}}{\sum \text{LnX}}$$

where: B = Exponent corresponding to the composite learning rate
Y = Normalized lot average unit cost
X = Computed algebraic lot midpoint corresponding to Y

The composite learning rate was determined using the following equation

Learning rate = Antilog(0.30103 B + 2)

Using the composite learning rates, theoretical first-unit costs were calculated for:

Item producers not included in the composite learning rate determination for which production cost histories were available.

Component items for which historical production cost data were not available necessitating estimates.

b. Results

(1) Composite learning rates

The composite learning rates developed are as follows:

COMPOSITE LEARNING RATES

Component	Composite Learning Rate	Range	Number Used	Not Used	Not Usable	Total
Projectile	92.6%	83.0 - 98.9	35	10	70	115
HE						
HEAT						
Full-Bore AP						
TP						
Case	94.3%	82.1 - 99.1	20	7	9	36
Brass						
Steel						
Primer						
Percussion	89.7%	84.9 - 98.7	7	5	2	14
Electric	80.3%	80.3	1	0	5	6
Fuze	91.1%	84.0 - 99.2	17	9	33	59

For backup detail of this analysis, see Annex E.

Composite learning rates were not obtained for LAP, explosive fill, propellants, and links. This result substantiates the level-off concept, at least for these components. There is insufficient initial production data to establish where level-off occurred. Also, learning for APDS projectiles, as well as aluminum and combustible cases, could not be substantiated since the cost data for these components consist of unit cost estimates.

(2) Effects of production breaks on learning loss

An increase in the unit cost after a production break is defined as a loss of learning. For ammunition, there is overwhelming evidence that there is not a loss of learning as a result of breaks in production. The following statistical results have been gathered.

	Number of Breaks in Production		Loss of Learning Occurred	
	1 Year	More than 1 Year	1 Year	More than 1 Year
Projectiles	6	8	1	0
Cases	4	3	0	0
Primers	5	2	0	1
Fuzes	2	4	0	0
	17	17	1	1

This analysis shows that only two cases of learning loss resulted in thirty-four production breaks examined. Therefore, the estimator should not make adjustments for breaks in production.

(3) Effects of variation in production rate

Inspection of the historical procurement data leads to rejection of the hypothesis that the rate of learning is determined by the production rate. However, as will be seen in the CER portion, section IIIC3, production rate is a fairly good predictor of unit costs.

3. Development of Cost Estimating Relationships and Cost Factors

a. Description of Methods of Analysis

The cost estimating relationships (CER's) presented in this study were developed using the Biomedical Multiple Regression with Case Combinations computer program, BMDO3R. The computer program is a standard regression analysis package which allows the analyst the flexibility of transforming initial independent and dependent variables to test various equation forms against the desired dependent variable. Also, the analyst can combine independent variables in a logical manner to generate additional independent variables.

Regression analyses using appropriate physical and performance characteristics as independent variables and costs as the dependent variables were performed at the following ammunition component levels:

(1) LAP

(2) Projectile

(3) Explosive Fill

(4) Case

(5) Propellant

(6) Primer

(7) Link

(8) Fuze

CER's providing the best statistical results were further analyzed to determine whether the addition of another independent variable or the transformation of an existing variable improved the statistics.

Because of a relatively large quantity of independent variables including initial variables, variable combinations, and variable transformations, a multitude of ammunition component CER's resulted. To select the best one, the CER's were screened using the following criteria.

The cost-driving or independent variables must make sense. For example, generally the larger the bore size the greater the LAP cost.

The percentage of the total variation explained by the regression equation was required to be high enough to pass the F test at a 99 percent level of significance. If a CER passes the F test at this level of significance, it is interpreted to mean that the probability is less than 0.01 that the disparity between the calculated explained and unexplained variations is due to chance.

If two or more CER's met criteria above, the CER with the minimum mean absolute percent deviation (MAPD) was selected. MAPD is defined as

$$\frac{1}{N} \sum_{i=1}^{N} \left| \frac{Z_i - \hat{Z}_i}{Z_i} \right|$$

where: Z_i = actual dependent-variable value
$\hat{Z}_i$ = estimated dependent-variable value
N = number of observations

MAPD is interpreted as the average percent that the CER estimated values deviate from the actual values.

The coefficient of variation, defined as the ratio of the standard error of estimate to the mean of the actual dependent-variable values, was minimized. The coefficient of variation is used in comparing two or more CER's possessing the same dependent variable but with a different number of observations. It is emphasized that the dependent variable used in the coefficient of variation needs to be of exactly the same form when comparing CER's.

(1) Load, Assemble and Pack

Loading, assembling and packing (LAP) costs cover the costs of component assembly into a complete round ready for shipping. These costs include the packing (including steel-ready boxes) and other materials (bandling, dunnage, pallets, etc.) normally purchased by the GOCO plant.

The learning curve analysis on LAP costs, section IIIC2, failed to provide sufficient evidence for developing meaningful theoretical first-unit costs. The LAP regression analysis was, therefore, conducted using the average unit cost published in Annexes A and B as the dependent variable. When more than one LAP contractor produced the same item, the weighted average unit cost was used. Since no historical 20mm AP LAP costs were available, historical 20mm TP LAP unit costs were utilized in the AP regression analysis.

The data set used for this analysis covered fixed ammunition types in the AP, TP, HE and HEAT categories. Recoilless-rifle round data were excluded due to the differing physical performance principles. HE and HEAT data were combined into a single class since separate treatment would have resulted in insufficient data for both cases.

HIGH EXPLOSIVE (HE) and HIGH EXPLOSIVE ANTITANK (HEAT)

$$LnZ = -6.8639 + 2.1143 \, LnX \text{ or}$$

$$Z = 0.001045 \, X^{2.1143}$$

where: Z = Estimated unit cost in FY 74 dollars
X = Bore size in millimeters

Statistics:
Coefficient of determination = 0.952
Standard error of estimate in Ln form = 0.292
Mean absolute percent deviation = 16.1
Passes F test at 99 percent level of confidence
N = 15

CER DATA

Cartridge Nomenclature	Bore Size(mm)	Actual Unit Cost	Estimated Unit Cost
M56A3 HEI	20	$ 0.50	$ 0.59
M246 HEIT-SD	20	0.62	0.59
M48 HE	75	9.32	9.62
M352A1 HE	76	9.32	9.90
M348A1 HEAT	90	12.80	14.15
M393A2 HEPT	105	13.18	19.60
M456 HEAT-T	105	13.26	19.60
M71A1 HE	90	13.42	14.15
M71 HE	90	13.42	14.15
M431 HEAT-T	90	14.30	14.15
M431A1 HEAT-T	90	15.56	14.15
M431A2 HEAT	90	15.63	14.15
M496 HEAT	76	22.86	9.90
XM657 HET	152	42.88	42.85
XM409 HEAT-TMP	152	50.04	42.85

If the anticipated annual production rate significantly deviates from the mean of the rates included in this study's data base, it is recommended that the following formula be used:

$$LnZ = -4.1294 + 1.6819 \, LnX - 0.1743 \, LnY \text{ or}$$

$$Z = 0.01609 \, X^{1.6819} \, Y^{-0.1743}$$

where: Z = Estimated unit cost in FY 74 dollars
X = Bore size in millimeters
Y = Average annual production rate in thousands

Statistics:

Coefficients of determination

Multiple = 0.967

Partial

ZX.Y = 0.828

ZY.X = 0.303

XY = 0.732

Standard error of estimate in Ln form = 0.253

Mean absolute percent deviation = 18.4

Passes the F test at the 99 percent level of confidence

N = 15

CER DATA

Cartridge Nomenclature	Bore Size(mm)	Production Rate Per Year(k)	Actual Unit Cost	Estimated Unit Cost
M56A3 HEI	20	19,987	$ 0.50	$ 0.44
M246 HEIT-SD	20	1,357	0.62	0.71
M48 HE	75	48	9.32	11.68
M352A1 HE	76	48	9.32	11.94
M348A1 HEAT	90	120	12.80	13.52
M393A2 HEPT	105	82	13.18	18.73
M456 HEAT-T	105	102	13.26	18.03
M71A1 HE	90	180	13.42	12.60
M71 HE	90	180	13.42	12.60
M431 HEAT-T	90	120	14.30	13.52
M431A1 HEAT-T	90	120	15.56	13.52
M341A2 HEAT	90	120	15.63	13.52
M496 HEAT	76	25	22.86	13.38
XM657 HET	152	18	42.88	45.44
XM409 HEAT-TMP	152	43	50.04	39.04

ARMOR PIERCING (AP)

$$\text{Ln}Z = 2.9272 - 0.000002941\ X + 0.9583\ \text{Ln}Y$$

where: Z = Estimated unit cost in FY 74 dollars

X = Average annual production rate in thousands

Y = Projectile mass

Statistics:

Coefficients of determination

Multiple = 0.976

Partial

ZX.Y = 0.001

ZY.X = 0.940

XY = 0.606

Standard error of estimate in Ln form = 0.345
Mean absolute percent deviation = 23.5
Passes F test at 99 percent level of confidence
N = 9

CER DATA

Cartridge Nomenclature	Production Rate Per Year (k)	Projectile Mass	Actual Unit Cost	Estimated Unit Cost
M55A2 TPT	15,581	0.0068	$ 0.15	$ 0.15
M220 TPT	3,802	0.0071	0.17	0.16
M81A1 APT	1,200	0.0609	0.93	1.27
M392A2 APDST	65	0.7702	9.06	14.54
M339 APT	16	0.4503	10.15	8.69
M318A1 APT	31	0.7484	11.19	14.14
M388A1/A2 APT	180	0.4087	11.96	7.92
M61A1 APCT	180	0.4627	12.93	8.92
M77 APT	180	0.7267	14.10	13.75

An attempt was made to improve AP LAP estimating by combining the AP and TP data sets. This combination was made to increase data points to 21 from the nine points applicable to the AP rounds. However, this combination was statistically inferior to the AP LAP predictor.

TARGET PRACTICE (TP)

$$\text{Ln}Z = 4.1000 - 0.3247\ \text{Ln}X + 0.6453\ \text{Ln}Y \text{ or}$$

$$Z = 60.3403\ X^{-0.3247}Y^{0.6453}$$

where: Z = Estimated unit cost in FY 74 dollars
X = Average annual production rate in thousands
Y = Projectile mass

Statistics:
Coefficients of determination
Multiple = 0.972
Partial
ZX.Y = 0.639
ZY.X = 0.878
XY = 0.588
Standard error of estimate in Ln form = 0.351
Mean absolute percent deviation = 23.4
Passes F test at 99 percent level of confidence
N = 12

CER DATA

Cartridge Nomenclature	Production Rate Per Year (k)	Projectile Mass	Actual Unit Cost	Estimated Unit Cost
M55A2 TP	15,581	0.0068	$ 0.15	$ 0.10
M220 TPT	3,802	0.0071	0.17	0.17
M55A1 TPT	3,600	0.0416	0.29	0.54
M206A2 TPT	165	0.0083	0.58	0.52
M63 TP	3,600	0.0500	0.63	0.61
M91 TPT	1,200	0.0609	0.98	0.99
M490 TPT	339	0.6957	7.74	7.20
M456 TPT	51	0.6957	8.64	13.32
M340A1 TPT	60	0.4503	8.80	9.54
M353A1 TPT	238	0.7484	10.51	8.47
M393A1 TPT	69	0.7702	10.89	12.90
M411 TPT	53	1.3323	34.52	20.01

The LAP data for all types of rounds were combined to determine if increasing the level of aggregation would improve the predictive characteristics. Again, the combination was statistically inferior to the independent treatment of each type.

(2) Projectiles

Projectile metal parts costs include procurement costs of all body parts, excluding fuze parts, going into the LAP operations. The costs include profit and fees.

Since learning was encountered in HE, full-bore AP, and TP projectile procurements, section IIIC2, the CER dependent variable for these projectiles is the theoretical first-unit cost. When cost data for a projectile were available for more than one producer, the theoretical first-unit cost included in the regression analyses was an average of the theoretical first-unit costs of all producers. The theoretical first-unit costs were regressed against all reasonable independent variables resulting in bore size proving to be the best cost driver. The addition of velocity related variables, momentum and kinetic energy, was attempted to increase the predictive statistics. However, analysis of the equation forms resulted in illogical relationships since the theoretical first-unit cost varied inversely with the velocity related variables. These forms were, therefore, rejected.

The learning curve analysis, section IIIC2, yielded the conclusion that HEAT projectile procurement is affected by learning. Regression analyses utilizing either average unit cost or theoretical first-unit cost as the dependent variable, and bore size, projectile mass, muzzle velocity and combinations of the aforementioned as the independent variables were performed. However, no statistically acceptable CER resulted.

No learning rate was established for the procurement of APDS projectiles since the cost data are comprised of unit cost estimates. Hence, the cost predictors utilize unit cost as the dependent variable. With exception of the 20-35mm spin-stabilized, the APDS projectile cost predictors represent the methodologies used in estimating the unit cost data rather than statistically developed CER's.

The HE cost predictor includes projectiles for medium-bore, tank, recoilless rifle, and howitzer applications. The HEAT cost data includes projectiles for tank main-armament application. The full-bore AP cost predictor includes projectiles for medium-bore, tank, and howitzer applications. The APDS cost predictors cover spin-stabilized projectiles for medium-bore and tank applications in addition to fin-stabilized projectiles for tank main-armament application. The TP cost predictor includes projectiles for medium-bore and tank applications.

HIGH EXPLOSIVE (HE)

$$\ln Z = -1.6983 + 1.3739 \ln X \text{ or}$$

$$Z = 0.1830\, X^{1.3739}$$

where: Z = Estimated theoretical first-unit cost in FY 74 dollars
X = Bore size in millimeters

Statistics:

Coefficient of determination = 0.742
Standard error of estimate in Ln form = 0.501
Mean absolute percent deviation = 38.6
Passes F test at 99 percent level of confidence
N = 16

CER DATA

Projectile Nomenclature	Bore Size	Actual First-Unit Cost	Estimated First-Unit Cost
M56A3 HEI	20	$ 8.27	$ 11.22
M396A1 HE	57	94.45	47.30
M66 HE	75	127.51	68.96
M48 HE	75	62.86	68.96
M352/A1 HE	76	63.59	70.22
M71/A1 HE	90	68.88	88.59
M1 HE	105	44.04	109.49
M356 HET	120	183.86	131.53
XM657 HET	152	217.07	182.00
M107 HE	155	100.47	186.96
M449 HE	155	114.69	186.96
M549 HE	155	227.92	186.96
M483 HE	155	466.49	186.96
M437 HE	175	197.74	220.88
M106 HE	203	269.53	270.84
M404 HE	203	259.01	270.84

HIGH EXPLOSIVE ANTITANK (HEAT)

HEAT projectile data were examined to determine the possibility of developing a CER for HEAT projectiles with tank main-armament application. Regression analyses were performed utilizing bore size, projectile mass, muzzle velocity and combinations of the aforementioned as independent variables. However, no statistically acceptable CER's resulted. The following relevant cost data, in FY 74 dollars, are listed to assist the estimator.

Projectile Nomenclature	Bore Size(mm)	Average Unit Cost	Theoretical First-Unit Cost
M495 HEAT	76	$ 39.71	$ 66.69
M431 HEAT-T	90	31.10	124.22
M456A1 HEAT-T	105	34.54	90.61
M469 HEAT-T	120	92.44	138.65
M409 HEAT-MP	152	113.06	173.70

FULL-BORE ARMOR PIERCING (AP)

$$LnZ = -3.9018 + 1.7971\ LnX \text{ or}$$

$$Z = 0.02021\ X^{1.7971}$$

where: Z = Estimated theoretical first-unit cost in FY 74 dollars
X = Bore size in millimeters

Statistics:
Coefficient of determination = 0.943
Standard error of estimate in Ln form = 0.272
Mean absolute percent deviation = 17.2
Passes F test at 99 percent level of confidence
N = 8

CER DATA

Projectile Nomenclature	Bore Size	Actual First-Unit Cost	Estimated First-Unit Cost
M53 API	20	$ 4.47	$ 4.40
M81A1 APT	40	15.42	15.29
M61A1 APCT	75	38.59	47.33
M338A1/A2 APT	75	33.91	47.33
M339 APT	76	55.34	48.47
M318A1 APT	90	107.80	65.68
M77 APT	90	68.56	65.68
M358 APT	120	94.09	110.15

20-35MM SPIN-STABILIZED, ARMOR PIERCING, DISCARDING SABOT (APDS)

The 20-35mm spin-stabilized APDS projectile CER's were developed based upon cost estimates for depleted uranium and tungsten alloy penetrators of accepted design, both with and without a tracer cavity. The cost estimates utilized a direct labor overhead rate of 270 percent, G&A rate of 15 percent and profit rate of 12 percent.

Depleted Uranium

$$Z = (7.8372 + 2.2988T) - (0.6730 + 0.1897T)\ LnX + (223.7385 + 72.9148T)\ Y$$

Tungsten Alloy

$$Z = (8.6845 + 1.6398T) - (0.9030 + 0.1620T)\ LnX + (728.3217 + 111.8573T)\ Y$$

where: Z = Estimated unit cost in FY 75 dollars
X = Average annual production rate in thousands
Y = In-flight projectile mass
T = Tracer cavity conditional code
= 0 if without tracer cavity
= 1 if with tracer cavity

Statistics:

Depleted Uranium without Tracer Cavity

Coefficients of determination

Multiple = 0.991

Partial

ZX.Y = 0.951

ZY.X = 0.989

XY = 0.000

Standard error of estimate = 0.165

Mean absolute percent deviation = 2.3

Passes F test at 99 percent level of confidence

N = 16

CER DATA

Production Rate Per Year(k)	In-Flight Projectile Mass	Actual Unit Cost	Estimated Unit Cost
312	0.00389	$4.842	$4.843
832	0.00389	3.938	4.182
2,080	0.00389	3.352	3.566
4,160	0.00389	3.070	3.099
312	0.00759	5.706	5.670
832	0.00759	4.946	5.010
2,080	0.00759	4.452	4.394
4,160	0.00759	4.139	3.927
312	0.01298	7.180	6.876
832	0.01298	6.299	6.216
2,080	0.01298	5.649	5.600
4,160	0.01298	5.339	5.133
312	0.02083	8.547	8.633
832	0.02083	7.913	7.973
2,080	0.02083	7.174	7.356
4,160	0.02083	6.818	6.889

Depleted Uranium with Tracer Cavity

Coefficients of determination

Multiple = 0.989

Partial

ZX.Y = 0.953

ZY.X = 0.986

XY = 0.000

Standard error of estimate = 0.207

Mean absolute percent deviation = 2.4

Passes F test at 99 percent level of confidence

N = 16

CER DATA

Production Rate Per Year(k)	In-Flight Projectile Mass	Actual Unit Cost	Estimated Unit Cost
312	0.00326	$ 6.219	$ 6.149
832	0.00326	4.961	5.302
2,080	0.00326	4.234	4.512
4,160	0.00326	3.890	3.914
312	0.00638	7.141	7.074
832	0.00638	6.139	6.228
2,080	0.00638	5.499	5.438
4,160	0.00638	5.100	4.840
312	0.01102	8.811	8.451
832	0.01102	7.687	7.604
2,080	0.01102	6.860	6.814
4,160	0.01102	6.471	6.216
312	0.01750	10.272	10.373
832	0.01750	9.393	9.527
2,080	0.01750	8.542	8.736
4,160	0.01750	8.096	8.138

Tungsten Alloy without Tracer Cavity

Coefficients of determination

Multiple = 0.999

Partial

ZX.Y = 0.962

ZY.X = 0.999

XY = 0.000

Standard error of estimate = 0.195

Mean absolute percent deviation = 1.8

Passes F test at 99 percent level of confidence

N = 16

CER DATA

Production Rate Per Year(k)	In-Flight Projectile Mass	Actual Unit Cost	Estimated Unit Cost
312	0.00384	$ 6.196	$ 6.295
832	0.00384	5.166	5.410
2,080	0.00384	4.474	4.582
4,160	0.00384	4.139	3.956
312	0.00751	8.894	8.968
832	0.00751	7.912	8.083
2,080	0.00751	7.288	7.255
4,160	0.00751	6.889	6.629
312	0.01298	13.339	12.952
832	0.01298	12.102	12.066
2,080	0.01298	11.192	11.239
4,160	0.01298	10.751	10.613
312	0.02061	18.645	18.509
832	0.02061	17.603	17.624
2,080	0.02061	16.548	16.796
4,160	0.02061	16.015	16.170

Tungsten Alloy with Tracer Cavity

Coefficients of determination

Multiple = 0.998

Partial

ZX.Y = 0.964

ZY.X = 0.998

XY = 0.000

Standard error of estimate = 0.222

Mean absolute percent deviation = 1.9

Passes F test at 99 percent level of confidence

N = 16

CER DATA

Production Rate Per Year(k)	In-Flight Projectile Mass	Actual Unit Cost	Estimated Unit Cost
312	0.00323	$ 6.875	$ 6.922
832	0.00323	5.529	5.877
2,080	0.00323	4.752	4.901
4,160	0.00323	4.366	4.163
312	0.00631	9.467	9.510
832	0.00631	8.281	8.465
2,080	0.00631	7.522	7.489
4,160	0.00631	7.052	6.751
312	0.01090	13.792	13.366
832	0.01090	12.343	12.321
2,080	0.01090	11.281	11.346
4,160	0.01090	10.783	10.607
312	0.01731	18.882	18.752
832	0.01731	17.653	17.707
2,080	0.01731	16.468	16.731
4,160	0.01731	15.849	15.993

75-152MM SPIN-STABILIZED, ARMOR PIERCING, DISCARDING SABOT (APDS)

$$Z = \text{Antiln}\ (2.9061 + 0.009663X) + (85.67 + 90.66T)\left(\frac{Y}{0.2640}\right) + 20.68\ \left(\frac{Y}{0.2640}\right)^{0.6667}$$

where: Z = Estimated unit cost in FY 76 dollars

X = Full-bore size in millimeters

Y = In-flight projectile mass

T = Material type conditional code

= 0 if depleted uranium core

= 1 if tungsten alloy core

The above equation was developed based upon cost estimates for spin-stabilized APDS projectiles of accepted design over the full-bore size range of 75-152mm. Due to the design, the in-flight projectile mass is restricted to the range of 0.20 - 0.34 and the minimum full-bore size is 75mm. The equation can be used to estimate the cost of a spin-stabilized APDS projectile incorporating either depleted uranium or tungsten alloy as the core material.

The first term of the equation estimates the sabot cost including G&A and profit. A regression analysis was performed with sabot unit cost as the dependent variable and full-bore size as the independent variable. The sabot unit cost estimates are as follows.

	75mm	76mm	90mm	105mm	120mm	152mm
Material	\$16.03	\$16.22	\$19.15	\$22.85	\$27.11	\$38.02
Labor	12.33	12.43	14.04	15.84	17.60	21.39
G&A (20%)	5.67	5.73	6.64	7.74	8.94	11.89
Profit (10%)	3.40	3.44	3.98	4.64	5.37	7.13
Total	\$37.43	\$37.82	\$43.81	\$51.07	\$59.02	\$78.43

The sabot CER and statistics are summarized below.

$$\text{LnC} = 2.9061 + 0.009663\ B \text{ or}$$

$$C = \text{Antiln } (2.9061 + 0.009663\ B)$$

where: C = Estimated sabot unit cost in FY 76 dollars
B = Full-bore size in millimeters

Statistics:
Coefficient of determination = 0.999
Standard error of estimate in Ln form = 0.012
Mean absolute percent deviation = 1.0
Passes F test at 99 percent level of confidence
N = 6

CER DATA

Bore Size(mm)	Actual Sabot Unit Cost	Estimated Sabot Unit Cost
75	\$37.43	\$37.74
76	37.82	38.11
90	43.81	43.63
105	51.07	50.44
120	59.02	58.30
152	78.43	79.43

The second and third terms of the equation estimate the material and labor unit costs, respectively, including G&A and profit of the in-flight projectile. The terms, in effect, scale the in-flight projectile costs corresponding to the basic design with a mass of 0.2640 to costs of comparable designs over the mass range of 0.20 - 0.34. The material cost term includes a cost of \$0.73 for tracer and plug and disc assembly.

FIN-STABILIZED, ARMOR PIERCING, DISCARDING SABOT (APDS)

$$Z = \text{Antiln}(3.1417 + 0.009529X) + (116.91 + 52.80T)\left(\frac{Y}{0.2640}\right) + 16.73\left(\frac{Y}{0.2640}\right)^{0.6667}$$

where: Z = Estimated unit cost in FY 76 dollars
X = Full-bore size in millimeters
Y = In-flight projectile mass
T = Material type conditional code
= 0 if depleted uranium core
= 1 if tungsten alloy core

The above equation was developed based upon cost estimates for fin-stabilized APDS projectiles of accepted design over the full-bore size range of 60 - 152mm. Due to the design, the in-flight projectile mass is restricted to the range of 0.20 - 0.34. The equation can be used to estimate the cost of a fin-stabilized APDS projectile incorporating either depleted uranium or tungsten alloy as the core material.

The first term of the equation estimates the sabot cost including G&A and profit. A regression analysis was performed with sabot unit cost as the dependent variable and full-bore size as the independent variable. The sabot unit cost estimates are as follows.

	60mm	75mm	76mm	90mm	105mm	120mm	152mm
Material	$ 9.36	$12.00	$12.21	$15.27	$19.11	$23.55	$34.98
Labor	21.22	23.92	23.96	26.17	29.30	32.06	38.48
G&A (20%)	6.12	7.18	7.24	8.29	9.68	11.12	14.69
Profit (10%)	3.67	4.31	4.34	4.97	5.81	6.68	8.82
Total	$40.37	$47.41	$47.75	$54.70	$63.90	$73.41	$96.97

The sabot CER and statistics are summarized below.

$$\text{LnC} = 3.1417 + 0.009529\ B \text{ or}$$

$$C = \text{Antiln}\ (3.1417 + 0.009529\ B)$$

where: C = Estimated sabot unit cost in FY 76 dollars
B = Full-bore size in millimeters

Statistics:
Coefficient of determination = 0.998
Standard error of estimate in Ln form = 0.013
Mean absolute percent deviation = 0.9
Passes F test at 99 percent level of confidence
N = 7

CER DATA

Bore Size(mm)	Actual Sabot Unit Cost	Estimated Sabot Unit Cost
60	$40.37	$40.99
75	47.41	47.29
76	47.75	47.75
90	54.70	54.56
105	63.90	62.94
120	73.41	72.62
152	96.97	98.51

The second and third terms of the equation estimate the material and labor unit costs, respectively, including G&A and profit of the in-flight projectile. The terms, in effect, scale the in-flight projectile costs corresponding to the basic design with a mass of 0.2640 to costs of comparable designs over the mass range of 0.20 - 0.34. The material cost term includes a cost of $0.73 for tracer and plug and disc assembly.

TARGET PRACTICE (TP)

$$\text{Ln}Z = -5.5868 + 2.1305\ \text{Ln}X \text{ or}$$

$$Z = 0.003747\ X^{2.1305}$$

where: Z = Estimated theoretical first-unit cost in FY 74 dollars
X = Bore size in millimeters

Statistics:
Coefficient of determination = 0.951
Standard error of estimate in Ln form = 0.385
Mean absolute percent deviation = 32.0
Passes F test at 99 percent level of confidence
N = 10

CER DATA

Projectile Nomenclature	Bore Size	Actual First-Unit Cost	Estimated First-Unit Cost
M55A2 TP	20	$ 3.26	$ 2.22
M212 TPT	20	2.00	2.22
M221 TPT	20	1.43	2.22
M63 TP	37	10.43	8.22
M55A1 TPT	37	9.50	8.22
M91 TPT	40	12.82	9.70
M340A2 TPT	76	21.80	38.09
M353 TPT	90	37.96	54.61
M489 TPT	105	71.08	75.83
M411A1 TPT	152	269.01	166.78

(3) Explosive Fill

Explosive fill is placed within the projectile to achieve a desired target effect. The explosive fill cost predictors only cover the use of composition B, TNT, and in a very few instances, composition A-3.

A learning curve analysis did not provide sufficient evidence for the development of theoretical first-unit costs. The costs used are only from the latest years of manufacture because TNT production has undergone a dramatic change in technology. The manufacturing process has switched from the batch method to an automated method. Coincidentally, there has been a lowering of demand for TNT. And the cost of petroleum, of which TNT is a product, has risen faster than the escalation factors would indicate. The sum effect of these changes resulted in the decision to use the latest production prices rather than 1960 - 1970 historical costs.

The independent variable best suited for estimating explosive fill costs is bore size. Other factors affecting the explosive fill costs were not available for all rounds and, therefore, not suitable.

HIGH EXPLOSIVE (HE)

$$\mathrm{Ln}Z = -13.8378 + 3.0885\ \mathrm{Ln}X \text{ or}$$

$$Z = (9.7794 \times 10^{-7})\ X^{3.0885}$$

where: Z = Estimated unit cost in FY 74 dollars
X = Bore size in millimeters

Statistics:
Coefficient of determination = 0.895
Standard error of estimate in Ln form = 0.558
Mean absolute percent deviation = 36.9
Passes F test at 99 percent level of confidence
N = 24

CER DATA

Cartridge Nomenclature	Bore Size(mm)	Actual Unit Cost	Estimated Unit Cost
M56A3 HE	20	$ 0.01	$ 0.01
MK2 HE	40	0.06	0.09
M306A1 HE	57	0.24	0.26
M307A1 HE	57	0.17	0.26
M48 HE	75	0.59	0.60
M42A1 HE	76	3.87	0.63
M352 HE	76	0.63	0.63
M71A1 HE	90	0.92	1.06
M71 HE	90	0.63	1.06
M591 HE	90	0.90	1.06

Cartridge Nomenclature	Bore Size(mm)	Actual Unit Cost	Estimated Unit Cost
M323 HE	105	$ 1.88	$ 1.71
M1 HE	105	2.14	1.71
M413 HE	105	0.47	1.71
M548 HE	105	2.24	1.71
M3A1 HE	107	3.08	1.81
M329 HE	107	3.08	1.81
M469 HET	120	1.94	2.58
M356 HET	120	3.41	2.58
M657E2 HET	152	3.76	5.36
M101 HE	155	6.20	5.69
M107 HE	155	5.78	5.69
M549 HE	155	6.88	5.69
M103 HE	203	8.28	13.09
M106 HE	203	14.32	13.09

HIGH EXPLOSIVE ANTITANK (HEAT)

$$LnZ = -12.3829 + 2.6706 \text{ Ln}X \text{ or}$$

$$Z = (4.1896 \times 10^{-6})\ X^{2.6706}$$

where: Z = Estimated unit cost in FY 74 dollars
X = Bore size in millimeters

Statistics:
Coefficient of determination = 0.944
Standard error of estimate in Ln form = 0.150
Mean absolute percent deviation = 10.0
Passes F test at 99 percent level of confidence
N = 10

CER DATA

Cartridge Nomenclature	Bore Size(mm)	Actual Unit Cost	Estimated Unit Cost
M310A1 HEAT	75	$0.43	$0.43
M66 HEAT-T	75	0.43	0.43
M496 HEAT-T	76	0.47	0.44
M371 HEAT	90	0.74	0.69
M431 HEAT	90	0.52	0.69
M348A1 HEAT	90	0.67	0.69
M324 HEAT-T	105	1.32	1.05
M456 HEAT-T	105	0.92	1.05
M344A1 HEAT	106	1.20	1.07
XM409E5 HEAT-T	152	2.71	2.81

HIGH EXPLOSIVE PLASTIC (HEP)

$$\ln Z = -3.7946 + 0.05190\ X$$

where: Z = Estimated unit cost in FY 74 dollars
X = Bore size in millimeters

Statistics:
Coefficient of determination = 0.773
Standard error of estimate in Ln form = 0.424
Mean absolute percent deviation = 29.9
Passes F test at 99 percent level of confidence
N = 8

CER DATA

Cartridge Nomenclature	Bore Size(mm)	Actual Unit Cost	Estimated Unit Cost
M309A1 HEPT	75	$0.59	$1.10
M349 HEPT	75	2.07	1.10
M326 HEPT	105	6.08	5.23
M345 HEPT	105	6.25	5.23
M327 HEPT	105	3.27	5.23
M393A1 HEPT	105	5.18	5.23
M393A2 HEPT	105	5.35	5.23
M346A1 HEPT	106	6.25	5.51

In addition to treating the round types separately, HEAT, HE, and HEP rounds were combined into a single CER. Also, HE and HEP rounds were combined into a single CER. The results of these combinations were statistically inferior to the independent treatment of each type and are, therefore, not recommended.

(4) Cases

Case costs include the cost of procurement from vendors. The learning curve analysis, section IIIC2, yielded the conclusion that brass and steel case procurement is affected by learning. Therefore, the brass and steel case regression analyses used the theoretical first-unit cost as the dependent variable. The theoretical first-unit costs for cases having multiple producers are averages of all producers. No learning rate was established for the procurement of aluminum or combustible cases since the cost data are comprised of unit cost estimates. Hence, the cost predictors utilize unit cost as the dependent variable. The aluminum case cost predictor represents the methodology used in estimating the unit cost data rather than a statistically developed CER.

Independent variables considered include bore size, length, surface area, projectile mass, momentum, kinetic energy, production rate, and various combinations of the above. Although charge weight was considered, this would be difficult for the estimator to determine. Round pressure was considered but the data were incomplete. The cartridge cases were segregated into categories of brass, steel, aluminum and combustible.

The results achieved on brass and steel cases were poor for the primary independent variables. Significant results were achieved on brass cases using surface area as an independent variable. Surface area as defined in this study, is dependent on case length and bore size. The results of the regression derived from surface area are included secondarily because the CER is the best cost predictor when case length is known.

The brass case cost predictors include cases for fixed HE, HEAT, AP, and TP ammunition with medium-bore and tank main-armament applications. The steel case cost predictor includes cases for fixed HE, HEAT, AP, and TP ammunition with medium-bore, tank, and recoilless rifle applications. The aluminum case cost predictor covers cases for fixed ammunition with medium-bore application. The combustible case cost predictor covers cases for fixed ammunition with tank main-armament application.

BRASS

$$\mathrm{Ln}Z = 0.6833 + 0.02674\ X + 0.5731\ Y$$

where: Z = Estimated theoretical first-unit cost in FY 74 dollars
X = Bore size in millimeters
Y = Projectile mass

Statistics:

Coefficients of determination

Multiple = 0.870

Partial

ZX.Y = 0.430

ZY.X = 0.0551

XY = 0.822

Standard error of estimate in Ln form = 0.469

Mean absolute percent deviation = 40.3

Passes F test at 99 percent of confidence

N = 28

CER DATA

Case Nomen	Cartridge Nomenclature	Bore Size (mm)	Projectile Mass	Actual First-Unit Cost	Estimated First-Unit Cost
MK1A2	M54A1 HE/M55A1 TPT	37	0.0416	$ 2.52	$ 5.45
	M80 APT	37	0.0516	2.52	5.49
	M63 TP	37	0.0500	2.52	5.48
M103	M52 APIT	20	0.0087	3.58	3.40
	M55A2/M242 API	20	0.0068	3.58	3.39
	M56A3 HEI	20	0.0070	3.58	3.39
	M220 TPT	20	0.0071	3.58	3.39
	M246 HEIT	20	0.0085	3.58	3.40
M18	M338A1 APT	75	0.4087	9.55	18.60
	M48 HE	75	0.4565	9.55	19.11
M25	M81A1 APT	40	0.0609	10.33	5.98
M17	M54A1 HE/M55A1 TPT	37	0.0416	10.77	5.45
	M59 APC	37	0.0593	10.77	5.51
T27E2	M348A1 HEAT	90	0.4472	21.44	28.39
M88	M339 APT	76	0.4503	24.27	19.56
	M352A1 HE	76	0.4658	24.27	19.74
	M331A1/A2 HVAPDST	76	0.2553	24.27	17.49
M115	M392A1/A2 APDST	105	0.7702	36.29	51.03
	M494 APERS	105	0.9565	38.66	56.77
	M467/M468 TPT	105	0.7702	38.66	51.03
M19	M71A1 HE	90	0.7267	47.36	33.33
	M77 APT	90	0.7267	47.36	33.33
	M304 HVAPT	90	0.5202	47.36	29.61
	M332A1 HVAP	90	0.3863	47.36	27.42
M108	M353A1 TPT	90	0.7484	48.77	33.74
M111	M469 HEAT-T	120	0.9658	73.53	85.24
M109	M358 APT/M359 TPT	120	1.5807	128.31	121.25
	M356 HET	120	1.5652	128.31	120.18

The following CER is preferred if the cartridge case length is known.

$$\text{Ln}Z = -0.3630 + 0.00026\,X + 0.6096\,\text{Ln}Y$$

where: Z = Estimated theoretical first-unit cost in FY 74 dollars

X = Momentum

Y = Proxy Variable in square inches

Statistics:

Coefficients of determination

Multiple = 0.922

Partial

ZX.Y = 0.304

ZY.X = 0.695

XY = 0.636

Standard error of estimate in Ln form = 0.363

Mean absolute percent deviation = 31.3

Passes F test at 99 percent level of confidence

N = 28

NOTE: The proxy variable is defined as the bore area plus the bore circumference times the cartridge case length. The formula is:

$$\text{Proxy Variable} = \pi r^2 + 2\pi rL$$

where: r = Bore radius in inches
L = Cartridge case length in inches.

The millimeter-to-inch conversion factor is 0.03937.

CER DATA

Case Nomenclature		Cartridge Nomenclature	Momentum	Proxy Variable (in^2)	Actual First-Unit Cost	Estimated First-Unit Cost
MK1A2	37mm	M54A1 HE/M55A1 TPT	108.160	18.324	$ 2.52	$ 4.21
		M80 APT	94.170	18.324	2.52	4.20
		M63 TP	130.000	18.324	2.52	4.24
M103	20mm	M52 APIT	29.406	10.411	3.58	2.92
		M55A2/M242 API	22.984	10.411	3.58	2.92
		M56A3 HEI	23.660	10.411	3.58	2.92
		M220 TPT	23.998	10.411	3.58	2.92
		M246 HEIT	28.730	10.411	3.58	2.92
M18	75mm	M338A1 APT	866.440	135.047	9.55	17.33
		M48 HE	890.175	135.047	9.55	17.44
M25	40mm	M81/A1 APT	174.783	62.504	10.33	9.05
M17	37mm	M54A1 HE/M55A1 TPT	108.160	41.709	10.77	6.95
		M59 APC	121.565	41.709	10.77	6.98
T27E2	90mm	M348A1 HEAT	1,252.160	273.680	21.44	29.47
M88	76mm	M339 APT	1,440.960	221.634	24.27	27.22
		M352A1 HE	1,117.920	221.634	24.27	25.03
		M331A1/A2 HVAPDST	1,053.113	221.634	24.27	24.61
M115	105mm	M392A1/A2 APDST	3,735.470	329.132	36.29	62.90
		M494 APERS	2,582.550	329.132	38.66	46.61
		M467/M468 TPT	1,848.480	329.132	38.66	38.51
M19	90mm	M71A1 HE	1,744.080	273.680	47.36	33.49
		M77 APT	1,962.090	273.680	47.36	32.51
		M304 HVAPT	1,742.670	273.680	47.36	33.48
		M332A1 HVAP	1,496.913	273.680	47.36	31.40
M108	90mm	M353A1 TPT	2,245.200	273.680	48.77	38.15
M111	120mm	M469 HEAT-T	3,621.750	402.980	73.53	69.09
M109	120mm	M358 APT/M359 TPT	5,532.450	504.352	128.31	130.19
		M356 HET	3,913.000	504.352	128.31	85.45

STEEL

$$\mathrm{Ln}Z = 1.0625 + 0.02063\ X + 0.2022\ Y$$

where: Z = Estimated theoretical first-unit cost in FY 74 dollars
X = Bore size in millimeters
Y = Projectile mass

Statistics:
Coefficients of determination
Multiple = 0.543
Partial
ZX.Y = 0.332
ZY.X = 0.006
XY = 0.716
Standard error of estimate in Ln form = 0.444
Mean absolute percent deviation = 40.3
Passes F test at 99 percent level of confidence
N = 26

CER DATA

Case Nomen	Cartridge Nomenclature	Bore Size(mm)	Projectile Mass	Actual First-Unit Cost	Estimated First-Unit Cost
M204	M206A1 TPT	20	0.0083	$ 4.35	$ 4.38
M18B1	M338A2 APT	75	0.4087	6.81	14.76
M25B1	M81 APT	40	0.0609	8.05	6.68
M108B1	M318 APT/M353 TPT	90	0.7484	10.68	21.54
	M336 CSTR	90	0.7233	10.68	21.44
	M337 CSTR	90	0.6351	10.68	21.06
M171	M496 HEAT-T	76	0.2879	11.79	14.71
M115B1	M391A1/A2 APDST	105	0.7702	17.28	29.49
	M728 APDST	105	0.4435	17.28	27.60
	M724 TPDST	105	0.2658	17.28	26.63
M88B1	M339 APT/M340A1E1 TPT	76	0.4503	19.57	15.20
	M352A1 HE	76	0.4658	19.57	15.24
	M363 CSTR	76	0.4565	19.57	15.22
	M331A1/A2 HVAPDST	76	0.2553	19.57	14.61
M200	M580 APERST	90	0.6522	20.10	21.13
M93B1	M344A1 HEAT	106	0.5466	24.24	28.77
M19B1	M71/A1 HET	90	0.7267	28.39	21.45
	M31A1 APT	90	0.7484	28.39	21.55
	M332A1 HVAPT	90	0.3863	28.39	20.02
M148A1B1	M490 TPT	105	0.6957	29.77	29.05
M114A1	M431A1/A2 HEAT	90	0.4037	31.96	20.09
M94B1	M581 APERST	106	0.6670	41.32	29.48
	M344A1 HEAT	106	0.5466	41.32	28.77
	M346 HEPT	106	0.5435	41.32	28.75
M150B1	M467 TPT	105	0.7702	50.70	29.49
	M494 APERS	105	0.9565	50.70	30.65

ALUMINUM

$$Z = 0.001188\ X + 0.00002852\ X^3 + 122.9027\ Y^{-0.6590}$$

where: Z = Estimated unit cost in FY 75 dollars
X = Bore size in millimeters
Y = Average annual production rate in thousands

The above equation was developed based upon cost estimates for aluminum cases over a bore size range of 20 - 35mm and an annual production rate range of 1,300K - 10,400K. Based upon the methodology used in estimating the costs, the equation can be used if the independent variable values are outside of the ranges.

The first and second terms of the equation estimate the material portion, including G&A and profit, of the total unit cost. These terms do not represent a statistically developed CER but portray the method utilized in estimating the material costs. The case weight in pounds as a function of bore size in millimeters is

$$W = 0.00001231\ B^3$$

The material unit cost estimates without G&A and profit include the cost estimates for 7475 aluminum strip, raw material shipping, chemicals, and packing; from which the cost estimate for scrap allowance is deducted. The unit cost estimates for these items were developed based upon the following equations.

$$\begin{aligned}
\text{7475 Al strip} &= 1.247\ (1 + R)(1 + F)(1 + L)(W) \\
&= 1.247\ (1.30)\ (1.04)\ (1.06)\ (0.00001231\ B^3) \\
&= 0.0000219992\ B^3 \\
\text{Shipping} &= 0.03\ (1 + R)(1 + F)(1 + L)(W) \\
&= 0.03\ (1.30)\ (1.04)\ (1.06)\ (0.00001231\ B^3) \\
&= 0.0000005293\ B^3 \\
\text{Chemicals} &= 0.0005386\ B \\
\text{Packing} &= 0.0003834\ B \\
\text{Scrap} &= 0.10\ (C)\quad [(1 + R)(1 + F)\ -1]\ (W) \\
&= 0.10\ (0.90)[(1.30)\ (1.04)\ \ -1]\ (0.00001231\ B^3) \\
&= 0.0000003900\ B^3
\end{aligned}$$

where: R = Raw material scrap rate of 30 percent
F = Finished case rejection rate of 4 percent
L = LAP plant scrap rate of 6 percent
C = Case manufacturer scrap recovery rate of 90 percent
W = Finished case weight in pounds
= $0.00001231\ B^3$
B = Bore size in millimeters

$1.247 = 7475 aluminum strip cost per pound
$0.03 = Raw material shipping cost per pound
$0.0005386 = Chemical cost per bore size millimeter
$0.0003834 = Packing cost per bore size millimeter
$0.10 = Scrap allowance cost per pound

The estimated G&A and profit rates are 15 percent and 12 percent, respectively. Therefore, the material unit cost including G&A and profit is estimated as follows.

$$[(\text{Chemicals} + \text{Packing})\ 1.15]\ 1.12 = (0.0009220\ B)\ (1.2880)$$
$$= 0.001188\ B$$
$$[(\text{Al strip} + \text{Shipping-Scrap})\ 1.15]\ 1.12 = (0.00002214\ B^3)(1.2880)$$
$$= 0.00002852\ B^3$$

The third term of the equation estimates the labor portion, including overhead, G&A and profit, of the total unit cost. A regression analysis was performed with labor unit cost as the dependent variable and annual production rate as the independent variable. The labor unit cost estimates are as follows.

	1,300K/yr	2,600K/yr	5,200K/yr	10,400K/yr
Direct Labor	$0.2429	$0.1349	$0.0883	$0.0610
Overhead (270%)	0.6558	0.3642	0.2384	0.1647
G&A (15%)	0.1348	0.0749	0.0490	0.0339
Profit (12%)	0.1240	0.0689	0.0451	0.0312
Total	$1.1575	$0.6429	$0.4208	$0.2908

The labor CER and statistics are summarized below.

$$\text{Ln}C = 4.8114 - 0.6590\ \text{Ln}R \text{ or}$$

$$C = 122.9027\ R^{0.6590}$$

where: C = Estimated labor unit cost in FY 75 dollars
R = Average annual production rate in thousands

Statistics:
Coefficient of determination = 0.988
Standard error of estimate in Ln form = 0.079
Mean absolute percent deviation = 5.5
Passes F test at 99 percent level of confidence
N = 4

CER DATA

Production Rate Per Year (k)	Actual Labor Unit Cost	Estimated Labor Unit Cost
1,300	$1.1575	$1.0901
2,600	0.6429	0.6904
5,200	0.4208	0.4372
10,400	0.2908	0.2769

COMBUSTIBLE

$$\ln Z = 1.2865 + 0.01015\, X$$

where: Z = Estimated unit cost in FY 74 dollars
X = Bore size in millimeters

Statistics:
Coefficient of determination = 0.983
Standard error of estimate in Ln form = 0.037
Mean absolute percent deviation = 2.1
Passes F test at 99 percent level of confidence
N = 5

CER DATA

Bore Size(mm)	Actual Unit Cost	Estimated Unit Cost
60	$ 6.700	$ 6.656
76	7.850	7.830
90	9.100	9.025
105	9.970	10.509
120	12.660	12.237

The combustible cartridge case costs used in developing the above equation were estimated with the assumption that complete rounds would possess the current performance characteristics utilizing combustible cases. Combustible case costs were estimated for a 60mm case as well as cases with applications on the following complete rounds.

Bore Size(mm)	Cartridge Nomenclature
76	M352A1 HE
90	M71A1 HET
105	M467 TPT
120	M356 HET

(5) Propellants

The propellant cost covers the cost of propellant manufacturing only. The learning curve analysis, section IIIC2, failed to provide evidence of learning application to propellant costs; therefore, propellants were priced at the average unit cost shown in Annex A. When several producers made the same propellant, the weighted average cost was used. When there was more than one propellant for a given round, costs for all propellants were used. When cost data were unavailable for a specified web thickness of a given type of propellant, the cost data of the web thickness closest to the web thickness specified for a round were used.

The data used for this analysis covered fixed ammunition types. Below is a table showing the derivation of propellant costs per round in FY 74 dollars.

PROPELLANTS

Cartridge Nomenclature	Bore Size	Type of Propellant	Propellant Weight (lb)	Propellant Cost Per Pound	Actual Cost of Propellant
M220 TPT	20mm	WC 870	0.087	$ 0.920	$ 0.08
M242 HEIT	20mm	WC 870	0.085	0.920	0.08
M56A3 HEI	20mm	WC 870	0.085	0.920	0.08
M52E1 APIT	20mm	WC 870	0.085	0.920	0.08
M246 HEIT	20mm	WC 870	0.086	0.920	0.08
M206A1 TPT	20mm	CR 8325	0.110	1.682	0.19
M55 TPT	37mm	M1 SP	0.340	0.781	0.27
M63 TP	37mm	M1 SP	0.560	0.781	0.44
M81A1 APT	40mm	M1 MP	0.650	0.757	0.49
MK2 HEIT	40mm	M1 MP	0.720	0.757	0.49
M72 APT	75mm	M1 SP	1.900	0.781	1.48
M48 HE	75mm	M1 SP	1.930	0.781	1.51
M61A1 APCT	75mm	M1 MP	2.000	0.757	1.51
M352A1 HE	76mm	M6 MP	3.640	0.752	2.74
M363 CSTR	76mm	M6 MP	5.000	0.725	3.63
M496 HEAT	76mm	M6 MP	5.060	0.725	3.67
M348 HEAT	90mm	M1 MP	5.000	0.757	3.79
M71A1 HET	90mm	M1 MP	5.310	0.757	4.02
M467 TPT	105mm	M1 MP	5.900	0.757	4.47
M338A1/A2 APT	75mm	M17	2.100	2.258	4.74
M71 HET	90mm	M6 MP	7.300	0.725	5.29
M339 APT	76mm	M30 MP	5.600	1.015	5.68
M336 CSTR	90mm	M6 MP	8.000	0.752	6.02
M377 CSTR	90mm	M6 MP	8.500	0.725	6.16
M580 APERST	90mm	M6 MP	8.800	0.725	6.38
M353A1 TPT	90mm	M6 MP	8.600	0.752	6.47
M494 APERS	105mm	M6 MP	9.200	0.725	6.67
M431A1/A2 HEAT	90mm	M30 MP	8.250	0.947	7.81
M318A1 APT	90mm	M30 MP	8.600	0.934	8.03
M724 TPDS	105mm	M30 MP	9.000	0.925	8.33
M318 APT	90mm	M17	8.600	0.942	9.42
M456A1/E1HEAT-T	105mm	M30 MP	11.500	0.947	10.89
M392 APDS	105mm	M30 MP	12.000	0.925	11.10
M728 APDST	105mm	M30 MP	12.000	0.947	11.36
M469 HET	120mm	M6 MP	23.000	0.725	16.68
M356 HET	120mm	M31	12.400	1.709	21.19
M358 APT	120mm	M17	29.000	2.258	65.48

An initial survey was run on all the above data for the linear and curvelinear regression forms covering the logical independent variables. The following preferred predictor resulted.

$$LnZ = -10.5840 + 0.01571\ X + 0.7416\ LnY$$

where: Z = Estimated unit cost in FY 74 dollars
X = Bore size in millimeters
Y = Kinetic energy

Statistics:
Coefficients of determination
Multiple = 0.968
Partial
ZX.Y = 0.120
XY.X = 0.469
XY = 0.944
Standard error of estimate in Ln form = 0.332
Mean absolute percent deviation = 23.3
Passes F test at 99 percent level of confidence
N = 37

CER DATA

Cartridge Model	Bore Size(mm)	Kinetic Energy	Actual Unit Cost	Estimated Unit Cost
M220	20	40,557	$ 0.08	$ 0.09
M242/M55A2/M53	20	38,843	0.08	0.09
M56A3	20	39,985	0.08	0.09
M52E1	20	49,696	0.08	0.11
M246	20	48,554	0.08	0.10
M206A1	20	48,236	0.19	0.10
M55	37	140,608	0.27	0.30
M63	37	169,000	0.44	0.34
M81/A1	40	250,814	0.49	0.48
MK2/M91	40	250,814	0.55	0.48
M72	75	891,969	1.48	2.13
M48	75	356,641	1.51	2.23
M61A1	75	953,370	1.51	1.08
M352A1	76	1,341,504	2.74	2.93
M363	76	1,314,720	3.63	2.88
M496	76	1,814,130	3.67	3.66
M348	90	1,753,024	3.79	4.44
M71	90	2,648,822	4.02	6.03
M467/M393	105	2,218,176	4.47	6.69
M338	75	918,431	4.74	2.17
M71	90	2,648,822	5.29	6.03
M399/M340	76	2,305,536	5.68	4.37
M336	90	2,978,875	6.02	6.58
M377	90	2,763,479	6.16	6.22
M580	90	2,924,900	6.38	6.51

Cartridge Model	Bore Size(mm)	Kinetic Energy	Actual Unit Cost	Estimated Unit Cost
M353	90	3,367,800	$ 6.47	$ 7.21
M494	105	3,486,443	6.67	9.36
M431	90	3,149,365	7.81	6.86
M318	90	3,367,800	8.03	7.21
M724	105	3,389,282	8.33	9.17
M318/M353	90	3,367,800	9.42	7.21
M456/M490	105	5,156,007	10.89	12.51
M392	105	9,058,515	11.10	19.01
M728	105	4,856,857	11.36	11.97
M469	120	6,790,781	16.68	19.43
M356	120	4,891,250	21.19	15.23
M358/M359	120	9,681,788	65.48	25.27

(6) Primers

The cost of primers as collected for this study includes profit and fee. The costs used as dependent variables are the theoretical first-unit costs as derived in the learning analysis, section IIIC2.

Analysis of all regression forms used for all reasonable independent variables revealed only weak relationships at best. Since it is a common engineering practice to try to use an available production primer rather than to create a new design for a new family of ammunition, it is unlikely to find primers specifically related to a complete round's performance characteristics. The alternative to using CER's is to use broad averages or analogies with a similar primer. Fortunately, primers are a small part of the total round cost; therefore, the use of CER's is preferred even though variations may be quite wide.

PERCUSSION

$$\mathrm{Ln}Z = 2.7957 - 2.2678\ \mathrm{Ln}X + 1.3338\ \mathrm{Ln}Y \text{ or}$$

$$Z = 16.3741\ X^{-2.2678}\ X^{1.3338}$$

where: Z = Estimated theoretical first-unit cost in FY 74 dollars
X = Round application bore size in millimeters
Y = Round application momentum

Statistics:
Coefficients of determination
Multiple = 0.645
Partial
ZX.Y = 0.096
ZY.X = 0.226
XY = 0.972
Standard error of estimate in Ln form = 0.569
Mean absolute percent deviation = 44.3
Passes F test at 99 percent level of confidence
N = 17

CER DATA

Primer Nomenclature	Bore Size(mm)	Momentum	Actual First-Unit Cost	Estimated First-Unit Cost
M115	20	28.33	$ 1.70	$ 1.60
M1B1A2	57	554.92	3.29	7.80
M38A1	37	108.19	3.43	2.35
M23A2	40	174.78	3.43	3.73
M22A3	75	570.63	3.43	4.35
M38B2	40	174.78	5.21	3.73
M81	76	1,022.05	5.43	9.18
M68	76	1,117.92	5.43	10.34
M68	90	1,252.16	5.43	8.20

Primer Nomenclature	Bore Size(mm)	Momentum	Actual First-Unit Cost	Estimated First-Unit Cost
M62	76	1,095.60	$ 7.70	$10.07
M58	76	1,440.96	13.08	14.51
M58	90	2,245.20	13.08	17.87
M96	120	3,621.75	14.07	17.61
M79	90	1,594.62	18.37	11.32
M79	90	1,614.80	18.37	11.51
M28B2	90	1,744.08	36.63	12.76
M28B2	90	1,962.09	36.63	14.93

ELECTRIC

$$\text{Ln}Z = -14.1220 + 4.0538\ \text{Ln}X - 0.9031\ \text{Ln}Y \text{ or}$$

$$Z = (7.3603 \times 10^{-7})\ X^{4.0538}\ Y^{-0.9031}$$

where: Z = Estimated theoretical first-unit cost in FY 74 dollars
X = Round application bore size in millimeters
Y = Round application projectile mass

Statistics:
Coefficients of determination
Multiple = 0.797
Partial
ZX.Y = 0.399
ZY.X = 0.201
XY = 0.972
Standard error of estimate in Ln form = 0.748
Mean absolute percent deviation = 61.3
Passes F test at 99 percent level of confidence
N = 13

CER DATA

Primer Nomenclature	Bore Size(mm)	Projectile Mass	Actual First-Unit Cost	Estimated First-Unit Cost
M52A3B1	20	0.0068	$ 10.48	$ 12.54
M52A3B1	20	0.0070	10.48	12.21
M52A3B1	20	0.0087	10.48	10.04
M52A3B1	20	0.0089	10.48	9.84
M67	120	0.9658	59.50	203.75
M67	120	1.5652	59.50	131.75
M67	120	1.5807	59.50	130.58
M86	105	0.7702	277.07	145.47
M86	105	0.9565	277.07	119.62
M80A1	105	0.2658	280.28	380.23
M80A1	105	0.4435	280.28	239.47
M80A1	105	0.7702	280.28	145.47
M83	105	0.6957	453.91	159.47

(7) Links

The learning curve analysis, section IIIC2, failed to provide sufficient evidence that link production is affected by learning. Therefore, the weighted average unit cost for all producers was determined for each link. The table below shows these data.

Link Nomenclature	Bore Size	Quantity	Weighted Average Unit Cost in FY 74 dollars
M1	7.62mm	621,516,075	$0.0120
M13	7.62mm	5,091,158,064	0.0133
M9	12.7mm	169,074,544	0.0265
M15	12.7mm	68,001,281	0.0669
M14	20mm	245,684,556	0.1592
M22	20mm	1,500,000	0.1904
M12	20mm	85,329,748	0.2368
M17	20mm	2,624,000	0.3786
M16	40mm	43,402,720	0.2645

The above cost data were regressed against bore size. This regression showed the best form to be $Y = AX^B$, with a 0.802 coefficient of determination. Based on the F test, the coefficient of determination is significant at the 99 percent confidence level. However, further analysis resulted in a mean absolute deviation of 51.42 percent which is undesirably high. Inspection of the data indicated that other independent variables such as round weight and muzzle velocity would not be superior to bore size.

The costs were then grouped by bore size and an average unit cost for each was found. Using these averages as estimators, the mean absolute deviation is 28.17 percent. The following chart is the result.

Bore Size	Average Cost
7.62mm	$0.0127
12.7mm	0.0467
20mm	0.2413
40mm	0.2645

For rounds with bore sizes other than those shown above, interpolation is suggested. It is unlikely that links would be required on rounds with a bore size greater than 40mm.

(8) Fuzes

Fuze costs include the cost of procurement of metal parts in addition to the fuze LAP. In some instances, fuze metal parts are procured from a vendor and assembled at an Army ammunition plant.

The learning curve analysis, section IIIC2, yielded the conclusion that fuze procurement is affected by learning. Therefore, the fuze regression analyses used the theoretical first-unit cost of each fuze as the dependent variable. Theoretical first-unit costs for fuzes having multiple producers are averages of all producers.

The data used for these analyses covered fixed ammunition types in the AP, TP, HE and HEAT categories. Recoilless-rifle and mortar-round data were included in the initial runs and excluded in subsequent runs because their independent variables differed widely from other fixed-round independent variables. The results achieved, excluding recoilless rifles and mortars, were more significant for base-detonating and point-initiating-base-detonating fuzes.

An initial survey of all independent variables was conducted to determine the regression forms to be subjected to further research. The independent variables were segregated by fuze type into point detonating (PD), base detonating (BD), point initiating-base detonating (PIBD), mechanical time (MT), mechanical time, superquick (MTSQ), and combination of BD and PIBD as well as MT and MTSQ. Independent variables included bore size, mass, kinetic energy, momentum, and various combinations of the above.

Analysis of all forms revealed only weak relationships. The weakness of the relationship is most likely a result of the practice of using a single fuze for a wide range of ammunition.

POINT DETONATING (PD)

$$\text{Ln}Z = 14.0768 - 2.2258\ \text{Ln}X + 1.0590\ \text{Ln}Y \text{ or}$$

$$Z = 1{,}298{,}603\ X^{-2.2258}\ Y^{1.0590}$$

where: Z = Estimated theoretical first-unit cost in FY 74 dollars
X = Round application bore size in millimeters
Y = Round application projectile mass

Statistics:
- Coefficients of determination
  - Multiple = 0.583
  - Partial
    - ZX.Y = 0.103
    - ZY.X = 0.175
    - XY = 0.988
- Standard error of estimate in Ln form = 0.518
- Mean absolute percent deviation = 45.2
- Passes F test at 99 percent level of confidence
- N = 33

CER DATA

Fuze Nomen	Cartridge Nomenclature	Bore Size(mm)	Projectile Mass	Actual First-Unit Cost	Estimated First-Unit Cost
M505A3	M210 HEI	20	0.0088	$ 6.01	$10.99
	M242 HEI	20	0.0068	6.01	8.36
	M56A3 HEI	20	0.0070	6.01	8.62
	M246 HEI	20	0.0085	6.01	10.59
M572	M437 HE	175	0.5885	13.91	66.32
M71	MK2 HET	40	0.0609	17.55	18.22
XM720	XM657A2 HET	152	1.3106	21.10	24.07
M78	M1 HE	105	1.0248	28.77	42.26
	M107 HE	155	2.9503	28.77	54.43
	M106 HE	203	6.2112	28.77	65.68
M51A4/A5	M334 HE	75	0.3792	53.65	31.19
	M1 HE	105	1.0248	53.65	42.26
	M107 HE	155	2.9503	53.65	54.43
	M101 HE	155	2.9503	53.65	54.43
	M106 HE	203	6.2112	53.65	65.68
	M103 HE	203	7.4534	53.65	79.67
	M352A1 HE	76	0.4658	53.65	37.65
	M42A1 HE	76	0.3975	53.65	31.83
	M71A1 HE	90	0.7267	53.65	41.39
	M48 HE	75	0.4565	53.65	37.96
M557	M48 HE	75	0.4565	54.34	37.96
	M71A1 TP	90	0.7267	54.34	41.39
	M356 HET	120	1.5652	54.34	49.17
	M411 TPT	152	1.3323	54.34	24.50
	M1 HE	105	1.0248	54.34	42.26
	XM548 RAP HE	105	0.8851	54.34	36.19
	XM606 HE	105	0.8851	54.34	36.19
	M107 HE	155	2.9503	54.34	54.43
	XM549 RAP HE	155	2.9814	54.34	55.04
	M101 HE	155	2.9503	54.34	54.43
	M106 HE	203	6.2112	54.34	65.68
M48A3	M48 HE	75	0.4565	77.01	37.96
	M35A1 HE	76	0.4658	77.01	37.65

BASE DETONATING (BD)

$$LnZ = 0.6493 + 0.5905\ LnX + (2.0698 \times 10^{-7})\ Y$$

where: Z = Estimated theoretical first-unit cost in FY 74 dollars
X = Round application bore size in millimeters
Y = Round application kinetic energy

Statistics:
Coefficients of determination
Multiple = 0.685
Partial
ZX.Y = 0.330
ZY.X = 0.264
XY = 0.372
Standard error of estimate in Ln form = 0.260
Mean absolute percent deviation = 19.3
Passes F test at 95 percent level of confidence
N = 9

CER DATA

Fuze Nomen	Cartridge Nomenclature	Bore Size (mm)	Kinetic Energy	Actual First-Unit Cost	Estimated First-Unit Cost
M58	M63 HE	37	169,000	$15.61	$16.72
M66A2	M61A1 APCT	75	953,370	27.55	29.85
	M62A1 APCT	76	1,616,316	27.55	34.51
	M67 HEAT-T	105	698,750	27.55	34.54
M91A1	M66 HEAT	75	207,600	29.63	25.58
	M327 HEPT	105	1,228,700	29.63	38.54
M62	M66 HEAT-T	75	207,600	36.14	25.58
M578	M393 HEAT	105	2,218,176	54.37	47.30
M48A3	M393 HEAT	105	2,218,176	60.18	47.30

POINT INITIATING - BASE DETONATING (PIBD)

$$LnZ = -52.3486 + 11.5814\ LnX - 4.0205\ LnY \text{ or}$$

$$Z = (1.8420 \times 10^{-23})\ X^{11.5814}\ Y^{-4.0205}$$

where: Z = Estimated theoretical first-unit cost in FY 74 dollars
X = Round application bore size in millimeters
Y = Round application projectile mass

Statistics:
Coefficients of determination
Multiple = 0.897
Partial
ZX.Y = 0.823
ZY.X = 0.756
XY = 0.968

Standard error of estimate in Ln form = 0.265
Mean absolute percent deviation = 16.0
Passes F test at 97.5 percent level of confidence
N = 7

CER DATA

Fuze Nomen	Cartridge Nomenclature	Bore Size(mm)	Projectile Mass	Actual First-Unit Cost	Estimated First-Unit Cost
M509A1	M495 HEAT-T	76	0.2879	$ 21.23	$ 16.67
	M348 HEAT-T	90	0.4472	21.23	20.11
	M431A1 HEAT	90	0.4037	21.23	30.34
	M456 HEAT-T	105	0.6957	21.23	20.28
	XM622 HEAT-T	105	0.6941	21.23	20.47
	M469 HEAT-T	120	0.9658	21.23	25.46
XM539E4	M409 HEAT	152	1.3323	126.45	107.93

Other fuze types on which independent variables were attempted to be used as cost predictors were MT and MTSQ. None of the variables attempted were acceptable. Therefore, use of analyses and engineering methods appear to be the only methods available for estimating the cost of these fuze types. The following relevant cost information regarding these fuzes and a proximity fuze is published to assist the estimator.

	Theoretical First-Unit Cost
MECHANICAL TIME (MT)	
M563	$186.73
XM571	376.35
XM592	450.19
XM711	365.48
MECHANICAL TIME, SUPERQUICK (MTSQ)	
M548	208.23
M564	119.27
M577	208.94
PROXIMITY	
M514A1	118.60

b. Variables Used in Regression Forms Initially Attempted

The following matrices reflect the independent variables which were initially to be used as cost predictors. The method employed was regression analysis using both linear and curvilinear forms. In some instances, independent variables were used in combination, e.g., bore size and mass, and Ln bore size and Ln mass.

VARIABLES USED IN REGRESSION FORMS INITIALLY ATTEMPTED

DEPENDENT VARIABLES		Bore Size	Ln Bore Size	Bore Size & Prod Rate	Ln Bore Size & Ln Prod Rate	Proj Mass	Ln Proj Mass	Bore Size & Proj Mass	Ln Bore Size & Ln Proj Mass	Muzzle Vel	Ln Muzzle Vel	Bore Size & Muzzle Vel	Ln Bore Size & Ln Muzzle Vel	Bore Size Times Muzzle Vel	Ln Bore Size Times Ln Muzzle Vel	Momentum	Ln Momentum	Bore Size & Momentum	Ln Bore Size & Ln Momentum	Kinetic Energy (KE)	Ln KE	Bore Size & KE	Ln Bore Size & Ln KE	KE & Prod Rate	Ln KE & Ln Prod Rate	Bore Size, KE & Prod Rate	Ln Bore Size, Ln KE & Ln Prod Rate	Case Area	Ln Case Area	Bore Size, Mass & Case Area	Ln Bore Size, Ln Mass & Ln Case Area	Other	Ln Other
		INDEPENDENT VARIABLES																															
<u>LINKS</u>	Cost	X																															
	Ln Cost																																
<u>FUZES</u>																																	
PD Fuzes	Cost	X	X			X	X	X	X							X	X	X	X	X	X	X	X										
	Ln Cost	X	X			X	X	X	X							X	X	X	X	X	X	X	X										
BD Fuzes	Cost	X	X			X	X	X	X							X	X	X	X	X	X	X	X										
	Ln Cost	X	X			X	X	X	X							X	X	X	X	X	X	X	X										
PIBD Fuzes	Cost	X	X			X	X	X	X							X	X	X	X	X	X	X	X										
	Ln Cost	X	X			X	X	X	X							X	X	X	X	X	X	X	X										
MTSQ Fuzes	Cost	X	X			X	X	X	X							X	X	X	X	X	X	X	X										
	Ln Cost	X	X			X	X	X	X							X	X	X	X	X	X	X	X										
MT Fuzes	Cost	X	X			X	X	X	X							X	X	X	X	X	X	X	X										
	Ln Cost	X	X			X	X	X	X							X	X	X	X	X	X	X	X										
BD & PIBD	Cost	X	X			X	X	X	X							X	X	X	X	X	X	X	X										
	Ln Cost	X	X			X	X	X	X							X	X	X	X	X	X	X	X										
MTSQ & MT	Cost	X	X			X	X	X	X							X	X	X	X	X	X	X	X										
	Ln Cost	X	X			X	X	X	X							X	X	X	X	X	X	X	X										

VARIABLES USED IN REGRESSION FORMS INITIALLY ATTEMPTED

INDEPENDENT VARIABLES

DEPENDENT VARIABLES		Bore Size	Ln Bore Size	Bore Size & Prod Rate	Ln Bore Size & Ln Prod Rate	Proj Mass	Ln Proj Mass	Bore Size & Proj Mass	Ln Bore Size & Ln Proj Mass	Muzzle Vel	Ln Muzzle Vel	Bore Size & Muzzle Vel	Ln Bore Size & Ln Muzzle Vel	Bore Size Times Muzzle Vel	Ln Bore Size Times Ln Muzzle Vel	Momentum	Ln Momentum	Bore Size & Momentum	Ln Bore Size & Ln Momentum	Kinetic Energy (KE)	Ln KE	Bore Size & KE	Ln Bore Size & Ln KE	KE & Prod Rate	Ln KE & Ln Prod Rate	Momentum & Prod Rate	Ln Momentum & Ln Prod Rate	Case Area	Ln Case Area	Bore Size, Mass & Case Area	Ln Bore Size, Ln Mass & Ln Case Area	Other (Mass & Prod Rate)	Ln Other (Ln Mass & Ln Prod Rate)	Bore & Length	Ln Bore & Ln Length
EXPLOSIVE FILL																																			
All Rounds	Cost							X	X																										
	Ln Cost							X	X																										
HE Rounds	Cost	X	X			X	X	X	X																										
	Ln Cost	X	X			X	X	X	X																										
HEAT Rounds	Cost	X	X			X	X	X	X																										
	Ln Cost	X	X			X	X	X	X																										
HEP Rounds	Cost	X	X			X	X	X	X																										
	Ln Cost	X	X			X	X	X	X																										
HE & HEP Rounds	Cost							X	X																										
	Ln Cost							X	X																										
CASES																																			
Brass	Cost	X	X	X	X	X	X	X	X							X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X
	Ln Cost	X	X	X	X	X	X	X	X							X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X
Steel	Cost	X	X			X	X	X	X							X	X	X	X	X	X	X	X					X	X	X	X			X	X
	Ln Cost	X	X			X	X	X	X							X	X	X	X	X	X	X	X					X	X	X	X			X	X
PROPELLANTS	Cost	X	X			X	X					X	X	X	X	X	X			X	X														
	Ln Cost	X	X			X	X					X	X	X	X	X	X			X	X														
PRIMERS																																			
Percussion	Cost	X	X			X	X			X	X					X	X			X	X														
	Ln Cost	X	X			X	X	X		X	X					X	X	X	X	X	X	X	X												
Electric	Cost	X	X			X	X			X	X					X	X			X	X														
	Ln Cost	X	X			X	X		X	X	X					X	X		X	X	X		X												

VARIABLES USED IN REGRESSION FORMS INITIALLY ATTEMPTED

DEPENDENT VARIABLES		Bore Size	Ln Bore Size	Bore Size & Prod Rate	Ln Bore Size & Ln Prod Rate	Proj Mass	Ln Proj Mass	Bore Size & Proj Mass	Ln Bore Size & Ln Proj Mass	Muzzle Vel	Ln Muzzle Vel	Bore Size & Muzzle Vel	Ln Bore Size & Ln Muzzle Vel	Bore Size Times Muzzle Vel	Ln Bore Size Times Ln Muzzle Vel	Momentum	Ln Momentum	Bore Size & Momentum	Ln Bore Size & Ln Momentum	Kinetic Energy (KE)	Ln KE	Bore Size & KE	Ln Bore Size & Ln KE	KE & Prod Rate	Ln KE & Ln Prod Rate	Bore Size, KE & Prod Rate	Ln Bore Size, Ln KE & Ln Prod Rate	Case Area	Ln Case Area	Bore Size, Mass & Case Area	Ln Bore Size, Ln Mass & Ln Case Area	Other	Ln Other
LOAD, ASSEMBLE & PACK (LAP)																																	
All Rounds	Cost	X	X	X	X	X	X									X	X			X	X			X	X	X	X						
	Ln Cost	X	X	X	X	X	X									X	X			X	X			X	X	X	X						
HE Rounds	Cost	X	X	X	X	X	X									X	X			X	X												
	Ln Cost	X	X	X	X	X	X									X	X			X	X												
AP Rounds	Cost	X	X	X	X																												
	Ln Cost	X	X	X	X																												
TP Rounds	Cost	X	X	X	X	X	X									X	X			X	X												
	Ln Cost	X	X	X	X	X	X									X	X			X	X												
AP & TP Rounds	Cost	X	X	X	X	X	X									X	X			X	X												
	Ln Cost	X	X	X	X	X	X									X	X			X	X												
HE & AP Rounds	Cost	X	X	X	X	X	X									X	X			X	X												
	Ln Cost	X	X	X	X	X	X									X	X			X	X												
PROJECTILES																																Mass & Vel	Ln Mass & Ln Vel
HE Rounds	Cost	X	X			X	X	X	X			X	X			X	X	X	X	X	X	X	X									X	X
	Ln Cost	X	X			X	X	X	X			X	X			X	X	X	X	X	X	X	X									X	X
AP Rounds	Cost	X	X			X	X	X	X																								
	Ln Cost	X	X			X	X	X	X																								
TP Rounds	Cost	X	X			X	X	X	X			X	X			X	X	X	X	X	X	X	X									X	X
	Ln Cost	X	X			X	X	X	X			X	X			X	X	X	X	X	X	X	X									X	X
HEAT Rounds	Cost	X	X			X	X	X	X																								
	Ln Cost	X	X			X	X	X	X																								
CSTR Rounds	Cost	X	X			X	X	X	X																								
	Ln Cost	X	X			X	X	X	X																								
HE & TP Rounds	Cost	X	X			X	X	X	X																								
	Ln Cost	X	X			X	X	X	X																								

4. Transportation Costs

Determination of transportation cost for ammunition items has long been a problem. Historically, these costs have often been forcasted with gross percentage adjustments based upon standard prices. At other times, attempts have been made to use complex deterministic cost models. The Cost Analysis Division at ARMCOM has prepared a simplified regression approach to transportation cost modeling which allows routine low-cost updating for economic changes, a feature not available in previous efforts. The data and analysis contained in this section are provided as a by-product of this ARMCOM technical report entitled First Destination Transportation Cost for Ammunition, AMSAR-CPE 75-7, Oct 75.

The data were prepared as follows: End items and quantities were chosen by the ARMCOM Transportation and Traffic Management Directorate from the FY 75 Shopping List as provided by the ARMCOM Maintenance Directorate (dated 11 Nov 74, and updated 3 Mar 75). The items were selected as being representative of items shipped during the third quarter of FY 75.

For each of the items selected, the interim transportation cost (from component manufacture to LAP plant) was restructured by determining the most-likely transportation path, the mode, and the shipping weight, and by applying the appropriate transportation rates in effect at the time of shipments. Actual billing data cannot be used because of the inability to make a reliable breakout of individual end-item costs from Government bills of lading. The second-leg transportation cost from the LAP plant to the CONUS depot or port of embarkation (POE) was developed in the same manner.

For purposes of this publication, the selected data were limited to fixed and separate ammunition. Thus, the following data were extracted from the data of ARMCOM transportation study.

Cartridge Nomenclature	Unit Shipping Weight (lb)	Per-Item-Interim Cost	Per-Item-Second-Leg Cost	Total Cost
5.56mm M193	0.041358	$0.0001	$0.0009	$0.0010
7.62mm M80	0.100938	0.0002	0.0023	0.0025
20mm M220	0.988500	0.0127	0.0261	0.0388
40mm M406	0.831790	0.0278	0.0334	0.0612
40mm M407	0.812500	0.0290	0.0117	0.0407
105mm M490	73.466667	1.1419	1.6738	2.8157
105mm M393	71.166667	1.4744	2.3156	3.7900
106mm M344	58.100000	0.3558	2.3871	2.7429
106mm M346	63.000000	0.5181	2.5864	3.1045

The following cost data were developed using the unit shipping weight CER in the ARMCOM transportation study.

Cartridge Nomenclature	Unit Shipping Weight (lb)	Total Cost
120mm M356	158.50	$7.8212
120mm M359	163.67	8.0899
120mm M358	167.75	8.3023
152mm M411	101.00	4.8675
152mm M409A1	103.00	4.9690
152mm M625	106.00	5.1214

It is not reasonable to expect that the estimators will be able to use the unit-shipping weight as a cost driver because shipping weight is not available until the design is completed. Therefore, a proxy variable was obtained using projectile mass. The coefficient of determination between unit-shipping weight and projectile mass is 0.993 for these data. The cost data were regressed against projectile mass resulting in the following CER.

$$\text{Ln}Z = 1.5214 + 1.0029\ \text{Ln}X \text{ or}$$

$$Z = 4.5787\ X^{1.0029}$$

where: Z = Estimated unit cost in FY 75 dollars
X = Projectile mass

Statistics:
Coefficient of determination = 0.997
Standard error of estimate in Ln form = 0.179
Mean absolute percent deviation = 16.0
Passes F test at 99 percent level of confidence
N = 15

CER DATA

Cartridge Nomenclature	Projectile Mass	Actual Unit Cost	Estimated Unit Cost
5.56mm M193	0.0002	$0.0010	$0.0009
7.62mm M80	0.0007	0.0025	0.0031
20mm M220	0.0071	0.0388	0.0320
40mm M407	0.0116	0.0407	0.0524
40mm M406	0.0116	0.0612	0.0524
106mm M344	0.5450	2.7429	2.4910
105mm M490	0.6941	2.8157	3.1747
106mm M346	0.5435	3.1045	2.4841
105mm M393	0.7705	3.7900	3.5252
152mm M411	1.3323	4.8675	6.1052
152mm M409A1	1.3323	4.9690	6.1052
152mm M625	1.2981	5.1214	5.9480
120mm M356	1.5652	7.8212	7.1758
120mm M359	1.5807	8.0899	7.2471
120mm M358	1.5807	8.3023	7.2471

IV SPECIAL FINDINGS

A. NONRECURRING INVESTMENT

During an item's life cycle (LC) the first IPCE is required prior to the first Army System Acquisition Review Council (ASARC-1) decision point. IPCE-1 contains, among other cost elements, an estimate for IPF. The Project Manager for Munitions Production Base Modernization and Expansion, who has the responsibility for IPF, first enters the LC process of events through his involvement with producibility engineering and planning (PEP). This event occurs just after the second Defense Systems Acquisition Review Council (DSARC-2) decision point. The time between the IPCE-1 and PEP could be several years and the lack of a coordinated IPF effort could be detremental to the research and development program, since the IPF could inadvertently be grossly over or under stated in the IPCE.

An additional and directly related problem of mobilization base requirements (MBR) exists. The IPF estimate is sensitive to MBR or total ammunition quantity, mix, and annual acquisition rate. This quantitative information is required by both the system proponent and the IPE estimator prior to IPCE-1. Therefore, a timely and coordinated MBR statement is essential to realistic estimates prepared for the ASARC and DSARC. The MBR statement significantly affects cost elements in the investment recurring cost category.

It is recommended that the appropriate agencies be required to staff and resolve the problems cited above. It may be necessary to establish the mobilization plan as a requirement for completion of the decision coordinating paper.

B. ECONOMIC ORDER QUANTITY DETERMINATION

Following procurement of ammunition to fulfill the Authorized Acquisition Objective (AAO) and deployment of the user system to the field, consumption and replenishment of the training and practice ammunition inventory occur on a continuing, periodic basis to meet individual and unit training and service practice requirements. It is because of the long-term demand and resulting high-volume procurement of the latter requirements that the economics of order quantities becomes an important consideration. Investigation has revealed that current practice remains to base the procurement of operating ammunition on inventory drawdown, budget constraints, or both. Thus, to a large degree, the determination of order quantities is subjective rather than deterministic.

Ammunition experts agree that ammunition storage (inventory maintenance) costs can represent a significant element of expense. Storage costs can be reduced by maintaining lower average levels of inventory, but procurement related costs incurred by more frequent reordering of smaller quantities tend to offset the reductions obtained.

Although the annual demand or consumption rate of training and practice ammunition may be relatively precise, the procurement pattern can theoretically range from annual orders to meet the demand rate to procurement of the full life-cycle requirement in one order. Hence, the problem is to achieve a balance between procurement related and inventory related costs by means of varying the quantity ordered. This is a classic case of cost minimization.

A generalized inventory model, based on relevant summary-level costs, is presented below to illustrate the economic order-size concept. The model is shown graphically in Figure 1. The cost symbols used are defined as follows:

q = quantity (number of rounds) per order.

I = inventory related cost; i.e., the cost of holding one round in inventory for a unit of time. This factor may include the costs incurred in the provision and maintenance of storage facilities, physical maintenance of the inventory, and losses caused by obsolescence or damage experienced over time.

T = total time over which the training and practice ammunition is planned for procurement.

Q = the total number of rounds required over the time period T.

S = procurement related cost; i.e., the indirect cost per order incurred each time an order is procured (excluding price per round). This factor may include the administrative costs to place an order, the production setup costs per order and the indirect cost of production breaks (line shutdown, standby and line maintenance).

TC = total relevant cost; i.e., the sum of the procurement related and inventory related costs per order.

qm = economic order quantity; i.e., the order quantity at which the total cost, TC, is a minimum.

Given that Q rounds are required, the number of orders placed during time T is Q/q. If t is the time interval between orders, it follows that

$$t = \frac{T}{Q/q} = \frac{Tq}{Q} \qquad (1)$$

The model assumes that q rounds are in inventory at the beginning of the time interval t, and that the inventory is depleted at the end of the interval. Based on this assumption, the average inventory level during the time t is q/2. Hence, the inventory related cost per order is the average inventory level multiplied by the inventory related cost per round per unit of time multiplied by the time interval t, or

$$\text{Inventory related cost per order} = (q/2)\ It \qquad (2)$$

The time interval t can be expressed in terms of the total time T by substituting the right-hand side of equation (1) for t in equation (2).

$$\text{Inventory related cost per order} = \frac{q^2\ IT}{2Q} \qquad (3)$$

The total inventory related costs over the time period T is determined by multiplying the cost per order, equation (3), by the number of orders placed over time T, or Q/q.

$$\text{Total inventory related costs} = \frac{q^2\ ITQ}{2Qq} = IT(q/2) \qquad (4)$$

The total procurement related cost over the time period T is the procurement related cost per order, S, times the number of orders, Q/q.

$$\text{Total procurement related cost} = S(Q/q) \qquad (5)$$

The total cost, TC, is the sum of the total inventory related cost, equation (4), and the total procurement related cost, equation (5), or

$$TC = IT(q/2) + S(Q/q) \qquad (6)$$

The two right-hand terms in the total cost equation are shown graphically in Figure 1, in which the total inventory related cost increases with increases in order quantity and the total procurement related cost decreases with increases in order quantity. Graphically, the most economic order quantity is that quantity at which the curves for these costs cross, i.e., the minimum point of the total cost curve. Mathematically, this quantity can be determined by the process of differential calculus, in which the first derivative with respect to q of the total cost equation (6) is set equal to zero. As a result of this process, the economic order size is determined to be

$$qm = 2(SQ/IT)^{0.5} \qquad (7)$$

Models of the foregoing type are, for presentation purposes, general in nature and are based on several assumptions. The model described assumed the following:

1. The price per round is independent of order size, and can be excluded from the model. To the extent that the results of this study indicate that learning is not lost during production breaks, this assumption is true, however, other affects on price, such as inflation or quantity discounts for material, may render the assumption only partially true.

2. The demand rate is known with certainty and is constant over time T.

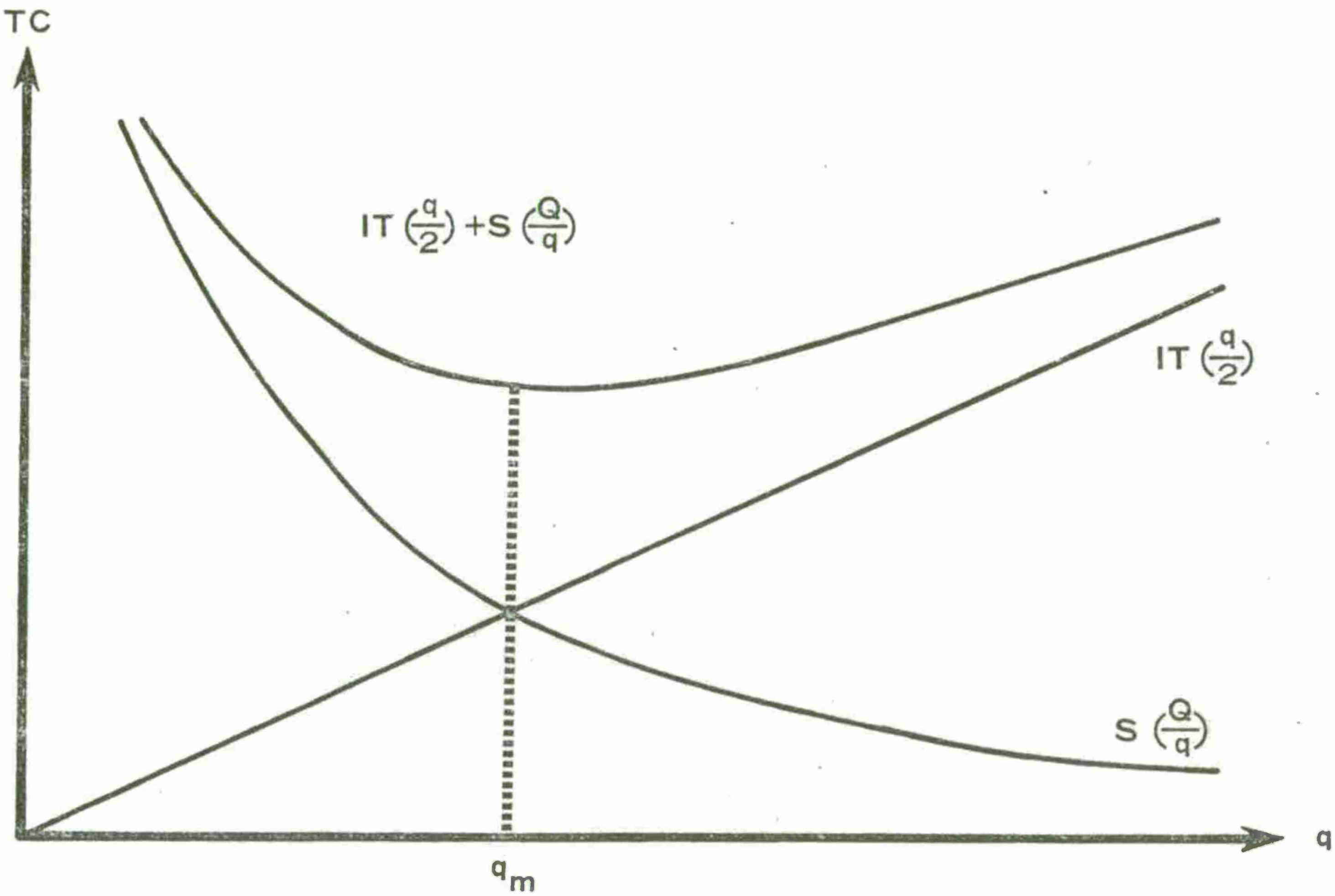

FIGURE 1 VARIATION OF TOTAL COST WITH ORDER QUANTITY

3. The procurement related cost per order is constant.

4. The inventory related cost varies linearly with the level of average inventory.

5. Procurement leadtime is a constant; i.e., stockouts (or depletion of inventory below a prescribed level) are not permissable.

6. The average inventory level is q/2 as described above.

Inventory models like this and similar to this are developed in a variety of management and production related publications, of which reference 89 is typical. However, since the assumptions on which such models are based may not be exact in practice, and the relevant costs in a general model are not explicitly defined, application requires extensive study and tailoring to accommodate the solution of actual inventory problems. Because the cost penalty of subjective order quantity determination may be significant over the life cycle of a given family of ammunition, it is recommended that a separate study be considered to:

a. Evaluate the feasibility of procuring training and practice ammunition in economic order quantities, and of identifying and quantifying the relevant costs.

b. Develop model(s) to determine the economic order quantity for specific applications.

C. AMMUNITION VELOCITY ESTIMATING EQUATIONS

Usage of the investment recurring CER's may require an estimation of either the muzzle velocity or the target velocity of a specific ammunition projectile. For example, suppose an armor piercing, discarding sabot projectile cost needs to be estimated. The estimator will be required to ascertain the kinetic energy needed at the target. The target velocity is determined based upon a known muzzle or initial velocity. The projectile mass can then be estimated since the target kinetic energy and target velocity are known. This projectile mass is then used as an independent variable in the armor piercing, discarding sabot CER.

The following equations provide the required analytic means to estimate the initial (or terminal) velocity of a direct fire system given the terminal (or initial) velocity of the projectile and its aerodynamic characteristics. Equations were developed to represent the three possible cases:

1. Firing at a target which is at the same altitude and neglecting gravity.

2. Firing at a target which is at the same altitude or slightly elevated and accounting for gravity.

3. Firing at a target which is below the gun and accounting for gravity.

The equations corresponding to each case are as follows.

	Estimate Initial Velocity	Estimate Terminal Velocity
Case I	$Vo = Ve^{kx}$	$V = Voe^{-kx}$
Case II	$Vo = a \tan\left[a\left(\frac{e^{kx}-1}{Ve^{kx}}\right) + \tan^{-1}\left(\frac{V}{a}\right)\right]$	$\left(\frac{1-e^{-kx}}{\frac{V}{a}}\right) + \tan^{-1}\left(\frac{V}{a}\right) = \tan^{-1}\left(\frac{Vo}{a}\right)$
Case III	$Vo = a \coth\left[\coth^{-1}\left(\frac{V}{a}\right) - a\left(\frac{e^{kx}-1}{Ve^{kx}}\right)\right]$	$\coth^{-1}\left(\frac{V}{a}\right) - \left(\frac{1-e^{-kx}}{\frac{V}{a}}\right) = \coth^{-1}\left(\frac{Vo}{a}\right)$

where:

Vo = Initial muzzle velocity ; (m/sec)

V = Projectile velocity at time t or range x; (m/sec)

t = Time since launch; (sec)

x = Range since launch; (m)

k = $\frac{Kd\ D^2 \rho}{M}$; (1/m)

Kd = $\frac{Cd\ \pi}{8}$; (dimensionless)

Cd = Zero-lift drag coefficient averaged over Mach numbers; (dimensionless)

D = Projectile caliber; (m)

ρ = Air density; (kg/m^3)

M = Projectile mass; (kg)

a = $\left(\frac{g \sin|\theta|}{k}\right)^{0.5}$; (m/sec)

g = Acceleration of gravity; $(9.8 m/sec^2)$

θ = Quadrant elevation; (degrees)

An iterative process is required to estimate the terminal velocity for Cases II and III.

Derivations of the initial velocity estimating equations follow.

Case I

The initial velocity estimating equation derived in this case considers constant aerodynamic drag and negligible gravitational affects. This approach also assumes a small quadrant elevation and thus a flat trajectory. The equation of motion is

$$\frac{dV}{dt} = \frac{-KdD^2 \rho V^2}{M} \qquad (1)$$

or $$\frac{dV}{dt} = -kV^2 \quad \text{where } k = \frac{KdD^2 \rho}{M} \qquad (2)$$

separating variables in (2) results in

$$\frac{dV}{V^2} = -kdt \qquad (3)$$

integrating and evaluating (3) yields

$$V^{-1} - Vo = kt \qquad (4)$$

transposing and reducing (4)

$$V^{-1} = kt + Vo^{-1} \qquad (5)$$

$$= Vo^{-1} (1 + Vokt) \qquad (6)$$

solving for t in (5) proceeds as follows

$$dx = \frac{dt}{kt + Vo^{-1}} \qquad (7)$$

integrating (7) and evaluating yields

$$x = \frac{1}{k} \left[Ln (kt + Vo^{-1}) - Ln (Vo^{-1}) \right] \qquad (8)$$

reducing (8) gives

$$kx = Ln (1 + Vokt) \qquad (9)$$

so $$e^{kx} = 1 + Vokt \qquad (10)$$

and thus $$t = \frac{e^{kx} - 1}{Vok} \qquad (11)$$

substituting for t in (6) yields

$$V = Voe^{-kx} \tag{12}$$

and finally

$$Vo = Ve^{kx}$$

This equation is an excellant estimator for projectiles whose terminal velocity is greater than Mach 1 (approximately 330m/sec) or for projectiles whose initial velocity is less than Mach 1.

Case II

The velocity estimating equation derived in this case considers constant aerodynamic drag in addition to non-negligible gravitational forces. The target is assumed to be at the same level or above the gun. The equation of motion is

$$\frac{dV}{dt} = -kV^2 - g \sin \theta \quad \text{where } \theta > 0 \tag{1}$$

solving for V in (1)

$$\frac{dV}{dt} = -k \left(V^2 + \frac{g \sin \theta}{k} \right) \tag{2}$$

substituting $a^2 = \frac{g \sin \theta}{k}$

$$\frac{dV}{dt} = -k \, (V^2 + a^2) \tag{3}$$

separating variables in (3) yields

$$\frac{dV}{V^2 + a^2} = -kdt \tag{4}$$

integrating (4)

$$\int_{Vo}^{V} \frac{dV}{V^2 + a^2} = \int_{o}^{t} -kdt \tag{5}$$

where $$\int_{Vo}^{V} \frac{dV}{V^2 + a^2} = \frac{1}{a} \tan^{-1} \left(\frac{V}{a} \right) \Bigg]_{Vo}^{V}$$

and $$\int_{o}^{t} -kdt = -kt \Bigg]_{o}^{t}$$

this yields

$$\frac{1}{a} \tan^{-1}\left(\frac{V}{a}\right) - \frac{1}{a} \tan^{-1}\left(\frac{Vo}{a}\right) = -kt \tag{6}$$

and

$$\tan^{-1}\left(\frac{Vo}{a}\right) = akt + \tan^{-1}\left(\frac{V}{a}\right) \tag{7}$$

taking the tangent of both sides yields

$$\frac{Vo}{a} = \tan\left[akt + \tan^{-1}\left(\frac{V}{a}\right)\right] \tag{8}$$

so

$$Vo = a \tan\left[akt + \tan^{-1}\left(\frac{V}{a}\right)\right] \tag{9}$$

Since t, the time of flight, may be unknown, then x, the range, must be determined in terms of t. Equation (11) from Case I for negligible gravitation affects is

$$t = \frac{e^{kx} - 1}{Vo\ k} = \frac{e^{kx} - 1}{Vke^{kx}} \tag{10}$$

and finally substituting (10) for t in (9)

$$Vo = a \tan\left[a\left(\frac{e^{kx} - 1}{Ve^{kx}}\right) + \tan^{-1}\left(\frac{V}{a}\right)\right]$$

This substitution is necessary because solving for t in (6) yields a function t(x) which involves Vo. Therefore, solving for Vo for a given V and x must be done parametrically. The substitution provides a good approximation. There is an error equal to the increase or decrease in time caused by the gravitational affects on the projectile over distance x. However, the correction factor again involves Vo and for estimation purposes this factor is assumed to be zero.

This equation estimates initial velocity when the gun is firing at aerial targets or at targets at the same altitude and considers gravity.

Case III

The velocity estimating equation derived in this case is similar to that developed in Case II, however in this case the target is always below the gun. The equation of motion is

$$\frac{dV}{dt} = -kV^2 - g \sin(-\theta) \text{ where } \theta > 0 \tag{1}$$

so $$\frac{dV}{dt} = -kV^2 + g \sin \theta \tag{2}$$

setting $a^2 = \frac{g \sin \theta}{k}$ and separating variables in (2) gives

$$\frac{dV}{V^2 - a^2} = -kdt \tag{3}$$

integrating and evaluating at V and Vo yields

$$-kt = \frac{-1}{a} \coth^{-1}\left(\frac{V}{a}\right) + \frac{1}{a} \coth^{-1}\left(\frac{Vo}{a}\right) \tag{4}$$

so $$-akt + \coth^{-1}\left(\frac{V}{a}\right) = \coth^{-1}\left(\frac{Vo}{a}\right) \tag{5}$$

taking hyperbolic cotangents of both sides of (5) yields

$$Vo = a \coth\left[\coth^{-1}\left(\frac{V}{a}\right) - akt\right] \tag{6}$$

and finally substituting

$\frac{e^{kx} - 1}{Vke^{kx}}$ for t in (6) gives

$$Vo = a \coth\left[\coth^{-1}\left(\frac{V}{a}\right) - a\left(\frac{e^{kx} - 1}{Ve^{kx}}\right)\right]$$

where $\coth^{-1} x = \frac{1}{2} \text{Ln}\left(\frac{x + 1}{x - 1}\right), \quad x^2 \quad 1$

or $\coth^{-1}\left(\frac{V}{a}\right) = \frac{1}{2} \text{Ln}\left(\frac{\frac{V}{a} + 1}{\frac{V}{a} - 1}\right), \quad \frac{V^2}{a^2} \quad 1$

and $\coth x = \frac{e^x + e^{-x}}{e^x - e^{-x}}$

This equation estimates initial velocity when the gun is above the target and considers gravity.

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